JANUARY, 1961

Welding Journal

IN THIS ISSUE

See Page 41

Vapor-shielded Arc Welding at 200 ipm..... 13
Hard Surfacing of Blast Furnace Bells and Hoppers..... 18
Inert-gas Spot Welding for Aircraft and Missiles..... 25
Template Preparation for Oxygen Cutting..... 34
Studies of Hot Cracking in High-strength Weld Metals..... 1-s
Properties of Plasma-sprayed Materials..... 8-s
Electrode for Spatter-free Welding of Steel in CO_2..... 14-s
Welding of Ni-Cr-Fe Inconel for Nuclear Power Plants..... 22-s
Application of 2219 Aluminum to Missile Pressure Vessels..... 33-s
Brittle Fracture of Reactor Pressure-vessel Steel..... 41-s

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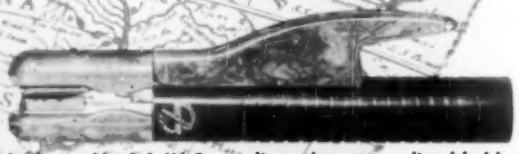

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Welding Journal

Technical Papers Items and Reports

Vapor-Shielded Arc Welding at 200 ipm, by R. A. Wilson 13
Hard Surfacing of Blast Furnace Bells and Hoppers, by Frank J. Gaydos and Nello Fragrasse 18
Inert-Gas Spot Welding in the Aircraft and Missile Industry, by R. L. Hackman 25
Principles of Template Preparation for the Oxygen Cutting Process, by L. M. Layden 34

Practical Welder and Designer

Bonuses from Welding with CO_2 and Flux-Cored Wire 41
Thin Skinned Avengers, by E. L. Trimble 42
Controls Wind Tunnel Air Flow at 2500°F 43

Society and Related Events

Press-Time News 2
Welding Zones 4
World-Wide Welding News 6
Editorial—World-wide Future in Welding, by F. G. Outcalt 11
Society News 44
Technical Papers Sessions 1961 AWS 42nd Annual Meeting 52
Section News and Events 56
New Members 71
News of the Industry 73
Personnel 78
Abstracts of Current Patents 90
New Literature 91
New Products 95
Reader Information Card 105
Index to Advertisers 106

Welding Research Supplement

Studies of Hot Cracking in High-strength Weld Metals, by H. W. Mishler, R. E. Monroe and P. J. Rieppel ... 1-s
Properties of Plasma-sprayed Materials, by M. A. Levinstein, A. Eisenlohr and B. E. Kramer 8-s
Research News 13-s
Electrode for Spatter-free Welding of Steel in Carbon Dioxide, by Everett Cushman 14-s
Arc Welding of a Ni-Cr-Fe Inconel Alloy for Nuclear Power Plants, by Jay Bland and W. A. Owczarski 22-s
Application of 2219 Aluminum Alloy to Missile Pressure-vessel Fabrication, by Clayton H. Crane and Whitney G. Smith 33-s
Brittle Fracture Characteristics of a Reactor Pressure Vessel Steel, by E. T. Wessel and W. H. Pryle 41-s

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PRESS-TIME NEWS ...about ...People ...Welding ...Products

Airco Demonstrates New Products

At a press conference held recently at the New York Coliseum, Air Reduction Sales Co. demonstrated two new brazing products.

A specially designed torch, dispenser and controls were used to fuse metallic powder to various parts for the purpose of hard surfacing. This process called "Aircospray" consists of a modified welding torch, a small control panel, a vibrator dispenser and a carrier gas for the powder. The modification of the torch consists in the addition of a tube placed externally or internally so that the metallic powder is introduced at the point of combustion, thus preventing flashback. The advantages cited are speed, a high degree of control over the thickness added, and a fused bond achieved in one operation. The unit is similarly used for brazing.

Also demonstrated was a new flux-cored silver brazing wire termed "Aircosil Fluxcor 45." Available in coils, the wire offers the advantages of placing the flux in the exact place required, at the right time and in the right amount—all in one operation.

The Aircospray unit recently demonstrated

Electroslag Welding to Highlight Midwest Conference

An evaluation of electroslag welding, a development recently introduced in this country, will be one of the highlights of the seventh annual Midwest Welding Conference at Chicago, Ill., on Feb. 1 and 2, 1961.

The conference, which is expected to attract nearly 300 welding engineers from industry, will be held on the campus of Illinois Institute of Technology. It is sponsored annually by Armour Research Foundation and the Chicago section of the AMERICAN WELDING SOCIETY.

Major topics to be discussed at the two-day meeting include "Welding of Aluminum Freight Cars," "Control of Fabricating Costs" and "Welding of Ultra-high Strength Steel Missile Cases."

The conference offers researchers in welding and welding engineers an opportunity to hear progress reports from industrial and technical experts.

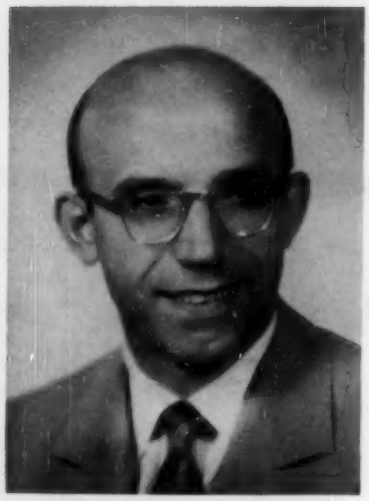
Inquiries concerning the conference should be forwarded to Harry Schwartzbart, supervisor of welding research, Armour Research Foundation, 10 W. 35th St., Chicago 16.

SESA Publication Makes Debut

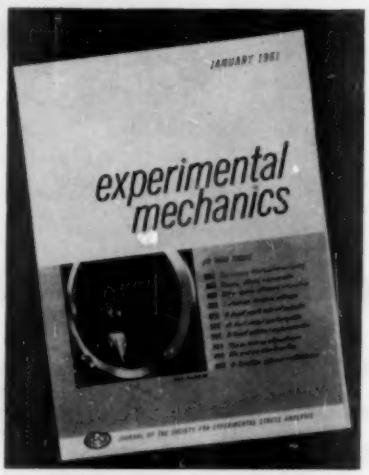
The Society for Experimental Stress Analysis (SESA) began 1961 by publishing a new monthly journal—*Experimental Mechanics*. Under the guidance of B. E. Rossi, former editor of the WELDING JOURNAL, the new publication contains papers by authorities in areas of interest to SESA and also carries news and other items regarding equipment, test machinery and instrumentation for conducting diverse investigations. Society and membership activities are also covered as are other subjects of related professional interest.

Editor Rossi is being assisted by C. H. Willer, who resigned from the WELDING JOURNAL in mid-December. Succeeding Mr. Willer on the JOURNAL staff is Robert H. Chamberlin, who studied public relations and journalism at Boston University where he was managing editor of the university newspaper and associate editor of the alumni magazine. More recently, he was editor of *Scope*, plant newspaper of the Electric Boat Division of the General Dynamics Corp., Groton, Conn.

BIRTH OF A NEW JOURNAL



Editor B. E. Rossi



Official SESA publication

Why is the motor generator still a "best-seller"?

Year after year the Hobart DC motor generator welder continues to be a "best-seller"—and when one examines the record it is easy to explain its popularity.

Hobart's MG has a good, basic design with no troublesome frills or gadgets. It's ruggedly built to stand abuse from weather and handling that results in long life and a high resale value.

Its extensive current range permits welding with the *widest* variety of electrodes. It is extremely versatile and due to separate excitation can easily be adapted to manual, semi-automatic, or fully automatic operations.

There's no intermittent line loading or power demand which can adversely affect other electrical equipment—yet its welding current is not affected by input voltage fluctuations. To all these benefits, add Hobart's accurate ampere range with 1000 combinations and dual control to assure the right current for every job; a remote control to save steps and valuable labor time; a simple linkage for changing from 220 to 440 volts and a toggle type polarity switch.

It is little wonder that the Hobart motor generator remains so popular! When you're in the market for a dependable DC welder, remember this "best-seller."

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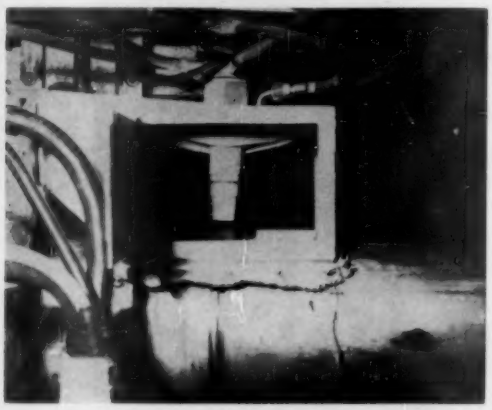
WELDING ZONES

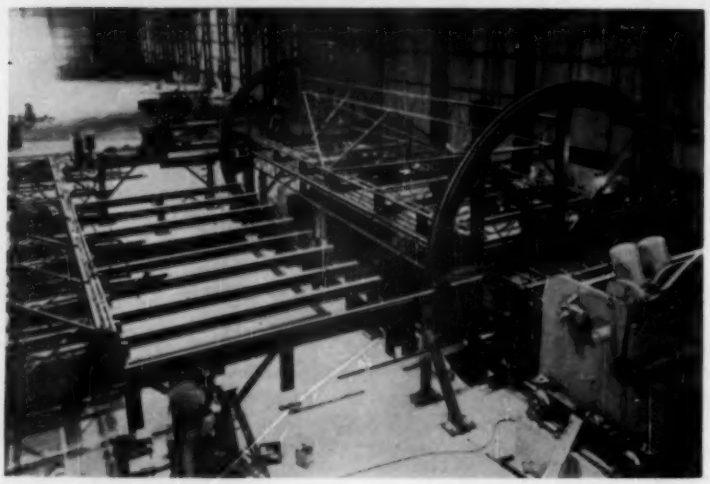
A 250,000-gal water tower being erected by Graver Tank & Mfg. Co., by starting at top and working down. As sections were completed, assembly was jacked to receive next course. When completed, "Aquatore" was 135 ft high.

"Surgically clean" describes the interior of this 25,000-gal Type 304 stainless-steel liquid oxygen storage vessel. Made by Struthers Wells Corp., Warren, Pa., for missile defense bases, the inner vessel weighs about 22 tons. (Courtesy Allegheny Ludlum Steel Corp.)



An automatic gas metal-arc machine specially designed to weld a 6-in. aluminum gas-transmission feeder line has a tiltable head. Pipe operates at 1000 psi. (Courtesy Aluminum Co. of America)

This 191-ft long automatic wire fabric welding machine is said to be capable of welding wire mesh at the rate of 60 tons a day. Made by National Electric Welding Machine Co., of Bay City, Mich., for Keystone Steel & Wire Co., Peoria, Ill.



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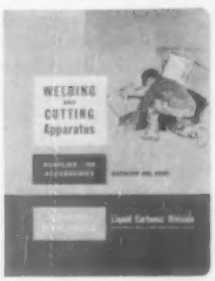

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WORLD-WIDE WELDING NEWS

By Gerard E. Claussen

EAST GERMANY

The East German *Zis Mitteilungen* for April 1960 contains abstracts of nine papers delivered at the First Production Welding Conference. Most of the papers deal with savings achieved through use of automatic submerged arc and CO_2 welding. Besides the abstracts there are ten papers on automatic arc welding.

1. Submerged arc welding of $^1/_5$-in. steel shells for compressed air tanks.

2. Flux backing is recommended for submerged arc welds made from one side. Cracking is avoided by holding the carbon content of the electrode to 0.12% max.

3. Nomograms relating wire speed voltage, amperage, weld volume and other factors in automatic and manual arc welding are explained.

4. Joint preparations are given for the CO_2 welding of pressure vessels.

5. Metallurgical and production problems in welding stainless steels are discussed briefly.

6. Ultrasonic echos and radiographs are compared for a series of welds. It is shown that neither method alone is adequate.

7. The method of fostering inventiveness in the Central Welding Institute is explained.

8. The work of East German standardizing committees is reviewed.

9. The resources of East Germany in welding operators and welding engineers are reviewed.

10. A program-controlled power supply for depositing intermittent arc welds has been developed.

•

The feature article of the March 1960 issue of the East German magazine *Schweisstechnik* is by B. E. Paton of Kiev, who describes Russian automatic welding equipment for submerged-arc electroslag and inert-gas-shielded arc welding. Portable equipment carried by the operator over his shoulder is used for wire up to $^1/_{16}$-in. diam for vertical welding. Strip electrode is used for electroslag titanium with argon protection, and also is used to deposit a wear-resistant surface layer on railroad rails with the submerged-arc process. By 1965 Paton estimates Russia will produce 850 million pounds of covered electrodes and 144,000 tons of submerged-arc flux a year.

Two research reports are in this issue. One shows that graphite or ferro-chromium powders can be fed to arc in the CO_2 stream in CO_2 welding with mild steel wire. The deposits contained 1.14% carbon or 2.74% Cr. The process was not economical because the CO_2 blew away most of the powder, and the alloy content could be controlled no closer than $^1/_2$%.

The second research paper describes still photographs of the CO_2 arc with $^1/_{16}$-in. steel wire at 200 amp, 29 v. Spatter originated in the puddle. The infrared film detected a sheath of hot gas surrounding the arc.

FRANCE

New Laboratory of the French Institute of Welding:

A part of the testing service of the French Institute of Welding has been transferred to 4 Rue Gambetta, in Saint-Ouen. The building is on the grounds of the Association for the Development of Techniques for the Engineering Industries. The new laboratory is devoted to nondestructive examination of welded parts and also unwelded parts.

The contract linking the National Conservatory of Arts and Trades to the Institute of Welding permits the Institute to make any nondestructive tests, whether the part is welded or not. Other types of tests are restricted to parts fabricated by welding or allied processes.

The new laboratory has the following equipment: (1) two ultrasonic defectoscopes for longitudinal and transverse waves; (2) one ultrasonic thickness meter for thicknesses over 0.02 in. with an accuracy of 0.0004 in; (3) 250 kv X-ray for radiographing steel up to 2 in. thick, (4) gamma ray equipment; (5) magnaflux equipment; (6) dye penetrant equipment; (7) salt spray corrosion equipment in accordance with French Standard P.N.X 41002; (8) hydraulic pressure tester up to 24,000 psi.

ITALY

The Italian Welding Institute's magazine for Jan Feb. 1960 features a paper on the arc welding of diesel engine frames made of steel containing 0.13 C, 0.73 Mn, 0.27 Si, 0.30 Cr. 0.40 Ni. Low hydrogen electrodes are used for root passes with semiautomatic or full-automatic submerged arc being used for the remaining layers to fill joints $^3/_4$ in. thick.

RUSSIA

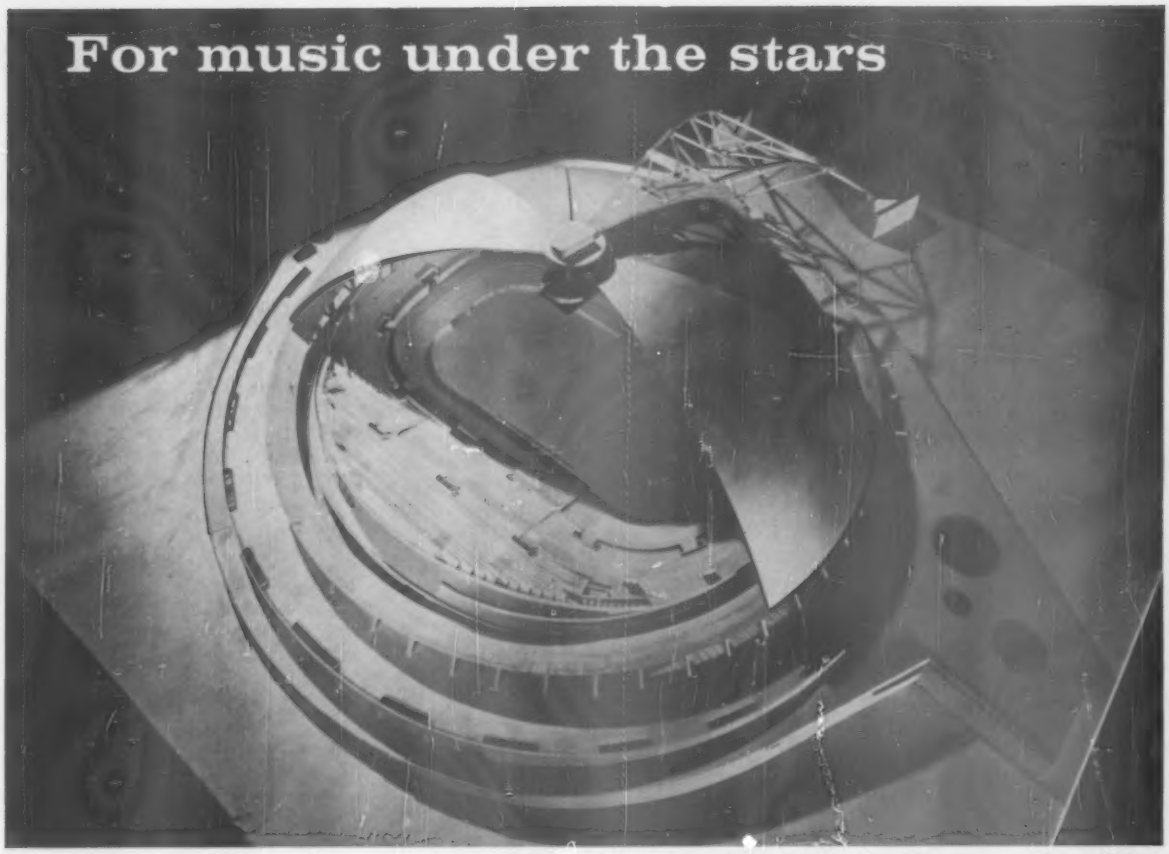
The following articles appeared in the February 1960 issue of *Svarachnoe Proizvodsvto*, Russia's production welding magazine:

1. The feature article by B. E. Paton summarized technical progress in welding in Russia. Special mention is made of reclamation by submerged arc welding of large worn objects such as blast furnace bells and hydroelectric turbine vanes.

2. Of three austenitic electrodes for welding stainless steels for steam turbines, the best from the standpoint of creep strength and ductility deposited metal containing 0.10 C, 19.5 Cr, 9.5 Ni, 0.95 Cb. The others contained no Cb, but had either 2.2 Mo, 0.75 V, or 1.8 Mo, 0.6 V, 0.9 W, 2.9 Co. Heat treatment of the weld at 1920 to 2200° F

Dr. GERALD E. CLAUSSEN is associated with Arcrods Corporation, Sparrows Point, Md.

For music under the stars



Dome of Pittsburgh Audi rium, in partly opened position, shows stadium within.

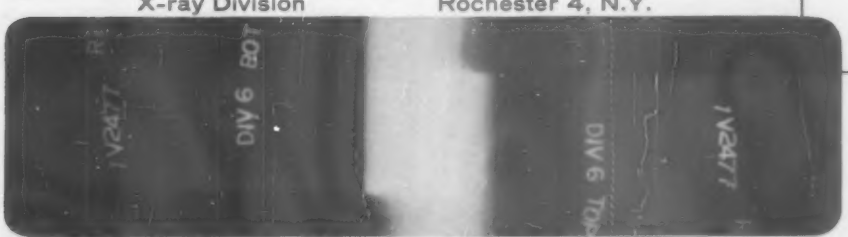
The 400-foot rollback dome of the new Pittsburgh Auditorium is supported by one huge welded cantilever backwork. Welds were proved sound by radiography.

The "leaves" of the great dome over Pittsburgh's new auditorium move on a circular track turning on an overhead pivot. There are no interior supports. When the dome swings open, the anchors of the backwork holding it up are under about 4,000,000-lb. tension, the buttress under 7,000,000-lb. thrust. Every weld in the system is critical.

To assure the integrity of all welds, U.S. Steel's American Bridge Division radiographed them using Kodak Industrial X-ray Film. This radiographic inspection provides a permanent record of the soundness of the welds.

If you would like to learn more about radiography in terms of your business, talk it over with an x-ray dealer, or write us for a Kodak Technical Representative to call.

GOOD NEWS! Kodak Industrial X-ray Film, Type AA and Type M, is now available in the new, convenient Ready Pack. Each sheet—sealed in a light-tight envelope ready for exposure—stays clean. After exposure a rip strip on the envelope makes it easy to open in the darkroom.



X-ray shows a sound weld in an I-beam flange supplied by American Bridge Division of the United States Steel Corporation.

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lowered the ferrite below 5%, which secured freedom from sigma embrittlement. The as-welded structure contained 3 to 10% ferrite for crack resistance.

3. Drop transfer from $^3/_{16}$-in. low-hydrogen electrodes was studied by embedding one or two probe wires 0.012 in. diam in the covering. The probes were connected to the core rod through an oscillograph. Three types of transfer were distinguished: (*a*) Large drops of which 80% transferred to the puddle. These shorted the probe to the core rod. (*b*) Large drops of which 50% transferred to the puddle. These shorted the arc, but only to a small extent shorted the probe. (*c*) Fine particles that were registered by arc voltage but not by the probe. As amperage increased from 150 to 250, drop frequency increased. Increasing the covering thickness from 0.053 to 0.067 in. reduced the weight of the individual drops.

4. A cruciform fillet test is suggested for evaluating cold cracking tendencies of welds made by submerged-arc or covered electrodes.

5. A theoretical and experimental determination of residual stresses in welding heat-treated duralumin (4.5 Cu, 1.5 Mg) is presented. Welds were made in $^3/_{16}$-in. sheet with $^1/_8$-in. tungsten electrode, 100 amp, ac, $8^1/_2$ ipm. The average tensile residual stress in the weld was found to be 26,000 psi, in close agreement with calculations based on temperature distribution and change in mechanical properties of duralumin with temperature.

6. The volt-ampere-length characteristics of underwater arcs were measured with and without addition of argon supplied by tubular electrode. Voltages were lower with argon, and current density was 3 to 4 times smaller with argon, and 12,000 without. Argon carried away a considerable part of the heat of the arc and made the Stefan-Boltzmann law inapplicable.

7. The microstructure of hot-pressure welds between plain-carbon and alloy steels revealed a band of ferrite at the joint in some instances. The ferrite was shown to be a result of oxidation.

8. The hard surfacing of mild steel shafts by the "Vibroarc" process under flux involved a $^3/_{64}$-in. electrode oscillating 24 times a second with an amplitude of 0.059 in. The electrode is deposited at 60–70 amp, 30 v at a wire feed rate of 55 ipm. Penetration is small and cracking was avoided.

9. A new type 347 electrode composition for submerged-arc welding with 480F6 flux contains 0.05–0.10 C, 18.5–20.5 Cr, 1.8–2.2 Mn, 9.0–10.5 Ni, 0.2–0.45 Si, 0.9–1.3 Cb, 0.03 maxP, 0.02 maxS. The flux contains 45–60 CaF_2, 16–23 CaO, 20–27 Al_2O_3. The claim is made that the new electrode provides weld metal with less tendency to high-temperature embrittlement and hot cracking than the present standard, which contains 1.2–1.5 Cb.

10. The interior of bushings for presses was hard faced with a tubular electrode depositing metal containing 0.36 C, 2.6 Cr, 9.7 W, 0.4 V with CO_2 shielding.

11. The composition and microstructure of deposits made with Stalinite powders by carbon arc are described. The hardness is in the range 70 to 80 R_c. The powders consist of various combinations of Fe, Mn and Cr, for example 56 Fe, 16 Cr, 16 Mn, 10 C, 2 Si.

12. A study of the electrical conductivity of copper welds showed that the best electrode for nitrogen arc welding contained 0.25–0.30% Si, remainder copper.

SWEDEN

The Swedish magazine ESAB's *Tidning Svetsaren* (No. 4, 1959) contains descriptions of welded construction cranes with horizontal lattice truss booms, and also welded tubular television masts.

SWITZERLAND

The sixth installment of Dr. Zeyen's reviews of literature on the welding metallurgy of ferrous metals and the new nonferrous metals was published in *Oerlikon Schweissmitteilungen*, No. 36, 1960. The 122-page review summarizes 724 references from mid-1958 to mid-1959.

WEST GERMANY

The April 1960 issue of the West German magazine *Schweissen und Schneiden* contains the following articles:

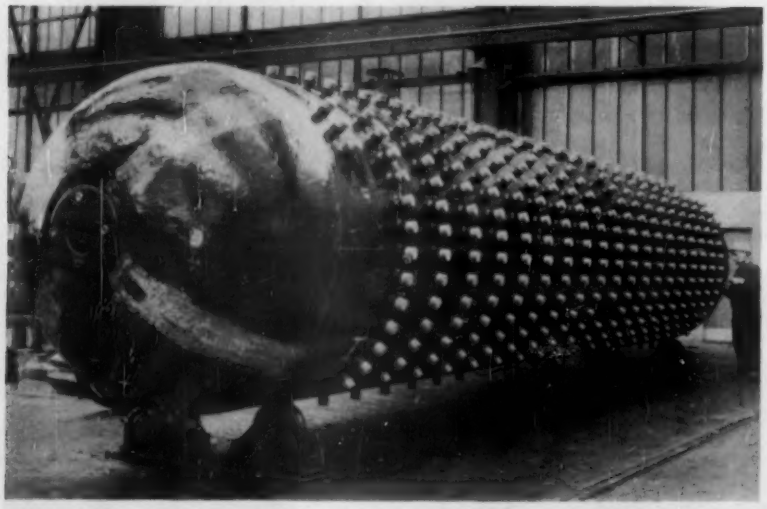
1. Nonmetallic inclusions were extracted electrolytically from submerged-arc weld metal to explain two observations: (*a*) The failure of weld metal containing normal sulfur to darken a sulfur print. This was ascribed to the extreme fineness of the sulfide inclusions in weld metal. (*b*) The tiny cracks sometimes observed in beads deposited at high travel speed. The cracks were observed in metal with a ratio of Mn to Si of 4.3 but not with a ratio of 1.0. The latter had 0.060% oxygen but the oxide inclusions were uniformly distributed. The former had only 0.30% total oxygen, but the inclusions were nonuniformly distributed and caused cracking.

2. The copper coating on arcair carbons was found to enter the arcair slag rather than the metal being cut. A cost comparison was made among the oxygen torch, oxyarc and arcair cutting processes for steels and cast iron.

3. Formulas are given for designing welded flanges for low-pressure service.

4. The exhibits of welding firms at the Hannover Industrial Fair, April-May 1960 are described.

WEST GERMANY



At Phoenix-Rheinrohr A. G., Düsseldorf, a 50-ton boiler drum

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ALL THIS FOR THE PRICE OF A TORCH ALONE!

This complete Vis-Arc inert gas welding torch outfit is now available from 50 amp aircooled to 500 amp water-cooled units.

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- short and long cap
- tungsten electrodes and
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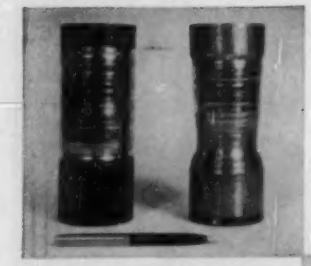
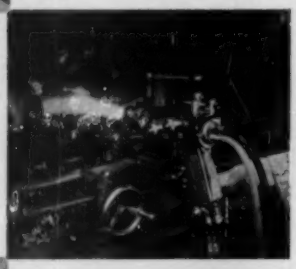


Pump sleeves last longer with Colmonoy hard surfacing. A carbon steel sleeve (left), protected with a Sprayweld overlay of Colmonoy No. 6 alloy, lasted three times longer than a stainless steel sleeve (right) in the same crude oil pump.

Small castings protect big equipment. Wear resistant Colmonoy alloy castings like this jet aircraft tail skid protect entire assemblies from being rendered inoperative due to failure of small critical parts suffering excessive wear.

Colmonoy Hard-Surfacing Alloys and Methods Make Equipment Last Longer

Six times the service at half the replacement cost. A conveyor screw for moving foundry sand lasted six times longer after hard-surfacing with Colmonoy No. 1 alloy (applied by arc welding), and WCR-100 (an oxy-acetylene rod).



Sprayweld Process makes smooth overlays fast. Glass bottle plants get at least 15 times longer glass plunger life by hard-surfacing their plungers with Colmonoy No. 6, one of five different Colmonoy Sprayweld Powder grades.

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World-wide Future in Welding

The attention recently directed to international trade balances and payments makes us in the welding industry in the United States conscious of our fortunate position. Years of emphasis on industrial production in our country have given special urge to the development of metal fabricating processes, including welding and cutting. The results of our efforts have been found useful and have been in demand throughout the world. Important examples of such developments include mechanized steel scarfing, submerged-arc welding, tungsten-arc welding, gas-shielded metal-arc welding and, more recently, carbon-dioxide magnetic-flux consumable-electrode welding as well as constricted tungsten-arc cutting. Research and process application development in widely separated areas, in several countries of Western Europe, in Great Britain, in Japan (and probably in the USSR) as well as in the United States, are adding much to the fund of knowledge about these processes first developed in our country.

Well established industrial companies with large money budgets for process development have been responsible for the successful introduction of many new processes. With a greater number of such companies in the United States than in any other country we may tend to assume that we shall have no difficulty maintaining a leading position. Inventions are made, however, by people—by individuals or by small groups of individuals—and there are no national or regional monopolies of inventive brains. In the increasingly virile industrial economies growing in many countries, there will be no lack of interest, money, or manpower to perfect and market new inventions.

Who will be the world leaders in the welding industry next year and in the years to follow? How will the future international balance of payments for welding knowledge, equipment and materials look?

The best future for the world welding industry may be international cooperation with less emphasis on international competition. This may be accomplished in several ways. Cooperative technical development agreements and programs between industrial organizations in the United States and in other countries offer a means of effectively using the increasing efforts of those interested in our industry throughout the world.

F. G. Outcalt

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Introducing a new process wherein simplicity and speed are the principal advantages when

Vapor-Shielded Arc Welding at 200 ipm

BY R. A. WILSON

The science of arc welding and the welding industry have arrived at their present position of development largely through the efforts of medium size, non-subsidized, private enterprises rather than through large research organizations or Government sponsorship. The development has been essentially one of practical application of processes and techniques discovered some time ago.

Most of these techniques were known as early as 1918. For example, U. S. Patent 1,589,017 filed in 1918 by J. C. Lincoln shows a knowledge of such fundamentals as steel filler metal, deep flux welding, CO_2 shielding, and other inert-gas techniques. Further refinement of these techniques would seem to offer limited possibilities only and suggests that progress must now come from a more basic approach than the "cut-and-dry" application of these well used fundamentals.

Several years ago development was initiated on a new welding technique. The starting point was a careful study of present manufacturing and construction job requirements so that these requirements, rather than existing processes, would govern development. Job demands in the field of welding sheet metal and plate up to $^1/_4$ in. thick seemed to be as follows:

A. Welding Method

1. Recognition must be given to industry's preference for a bare electrode, without control of extraneous elements such as loose flux, gas for shielding, or a covering that creates electrical contact problems.

2. High-travel speed is a "must" in light of today's economy. Thinking was projected in terms of double the speed of commonly used methods, with a high-current density, spray-type arc having "fast-follow" characteristics. At this time, maximum practical speeds were in the 90–100 ipm range.

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Paper presented at AWS National Fall Meeting held in Detroit, Mich., Sept. 28–Oct. 1, 1959.

Vapor shielding process being used to weld girth seam at end of a large tank—no external shielding medium is needed to protect arc area since part rotates under welding heads

3. Physical properties were established equivalent to those realized at the time on high speed applications.

4. It was considered essential to keep beads as wide as possible to handle poor fit-up; therefore, a preference was indicated for larger diameter wires which would also minimize the guiding problem and make for lower cost electrodes. The desirable minimum electrode diameter was set at $^1/_8$ in.

5. Weld cleaning had to be held to a minimum, and tolerance was desirable for a degree of dirty or rusty plate.

B. Methods of Wire Feed

1. Constant wire feed seemed the simplest approach for automatic feeding apparatus. Fully automatic heads would be developed first, but semi-automatic wire feeding for manual operation probably will be the larger field with ultimate process development.

C. Power Sources

1. Simple and uncomplicated, with low maintenance and without the need for specialized personnel, such as involved in electronic systems.

2. Freedom from incoming power supply variations—making motor generators the most obvious answer.

Coordinating the foregoing factors, a fully automatic process now has been developed and commercial installations have been made. The usual current range is 600–1100 amp and, on light-gage metal, speeds are 150–200 ipm. Laboratory studies confirm the feasibility of even higher speeds.

The Vapor-shielded Process

Use of cored, bare electrode to provide a vaporized shield and a clean surface for good electrical contact is the basic element of the new process.

The wire is tubular, filled with granular and chemical ingredients which boil in the arc heat and then condense to a vapor which both shields and deoxidizes the weld metal. Vapor proves to be a more effective and efficient shielding medium than a gas. The tubular form provides full shielding and deoxidizing without the addition of external flux or gas.

The process also meets or exceeds present cost and speed standards for automatic welding and provides required physical properties. The fast-follow arc action means that the molten weld puddle follows close to the arc and can be moved along the plate at exceptionally high speeds. While the arc is penetrating, it has less tendency to burn through at a given current than with small diameter gas-shielded electrodes.

A 750- or 1100-amp d-c power source is used with a constant wire feed in the automatic head. An action view of the head and controls is presented in the lead photograph. Here the girth seam at the end of a large tank is being welded, and no external shielding materials are needed to protect the arc area in that the part rotates under the head.

Scrap Hoppers

One application—interesting in that it involves an operation that is normally considered a hand welding job—is the welding of steep scrap hoppers at Roura Iron Works, Detroit, Mich. Previously this had been done manually because of the difficulty of holding submerged arc flux on the joints, some being corner welds and some with rather wide gaps to be filled.

Originally, the hoppers or buckets were mounted on a positioner. Efficient joint positioning produced arc speeds averaging about 18 ipm, with 100% operating factor. One man could place in the fixture and weld one complete hopper per hour after it had been assembled and tack welded. Production was doubled, however, following the introduction of new vapor-shielded process equipment mounted on a beam type welding manipulator. Production per man increased to 16 hoppers per day. This occurred despite the fact that setup time and positioning procedures were the same as before.

Installing two additional positioners as shown in Fig. 1 and introducing an additional man into the welding area further increased production by enabling the operator to keep the arc in operation more continuously. The second man now loads and unloads the additional positioners and carries out other jobs leaving the operator free to concentrate on producing the required welds. Production with the equivalent of $1^1/_2$ men currently is 27 to 30 units daily. Production of the hoppers, which vary in capacity, is temporarily confined to the high-volume $^3/_4$ yd and one yard sizes.

The joint around the top of the hopper calls for an angle stiffener set up to the top edge of the side plates. Initially it was thought that the poor fit of the flare groove joint would restrict process application. However, the ability of the vapor shielded process to handle poor fit conditions eliminated the problem. Moreover, 192 in. of this joint are made at an arc speed of 90 ipm with a machine setting of 700 amp and 27 v.

Fig. 1—Three welding positioners installed for production welding of scrap buckets at speeds four times faster than obtained with manual welding

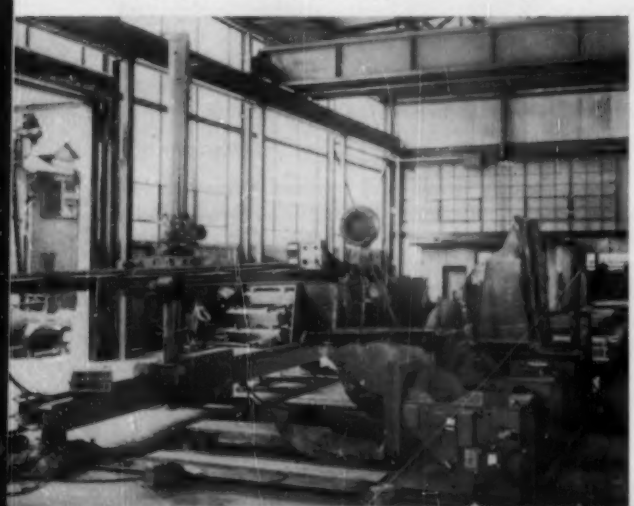

Fig. 2—Automobile axle housing mounted in welding unit for making seam around dust cap at center—flanges at ends are also welded automatically with vapor-shielded process

To increase welding efficiency, the start-stop button of the welding unit is removed from the control box and an extension added to permit the operator to carry the switch in his hand and control the equipment from the weld area. The welding manipulator's independent ram and carriage movement travels the head in and out for the side seam and longitudinally for the end seam. Rotating the hopper 90 deg, the operator makes the corner welds between the two $^3/_{16}$-in. thick plates positioned at right angles with one edge projecting beyond the other by $^1/_{16}$ in. Current setting is 900 amp at 27 v, and travel speed is again 90 ipm. Experience helped the operator devise the most efficient sequence of operations to minimize the effort and time.

The $^3/_{16}$-in. fillet on the bottom is made using a setting of 900 amp at 27 arc volts and a travel speed of 90 ipm. A total of 404 in. of welding is required in fabrication of the 1-cu yd hopper. Welding speed averages more than four times that of manual welding.

Welding Axle Housings

A major automobile manufacturer has adapted the vapor-shielded welding process to advantage in the fabrication of stamped axle housings. Applications include welding a reinforcing bead inside the housing butt-joint seam, welding the flanges to the ends of the housing, and welding on the dust cap at the center opening. Speed averages around 150 ipm on all three welds.

Flange and dust cap welders are converted submerged-arc fixtures, with few alterations beyond installing the new welding heads and controls. Welding the reinforcing bead is a new operation and requires a new fixture.

One of the chief reasons for changing from the submerged-arc technique was the elimination of large quantities of dust arising from the granular flux. This material, which was abrasive in character, caused occasional downtime production loss for maintenance of the automated equipment.

In the past, the weld joining the two heads of the housing was made with 60–70% penetration since it is difficult to back up these welds. However, a 100% weld was desirable in the area near the center of the housing at the reinforcing ring. Use of the vapor shield process made possible the approval of this weld to give a stronger section. Sequence of operations at the three stations begins when an operator takes a housing previously welded together from two half sections and places it in the reinforcing bead welder. Two heads simultaneously make two 2-in. welds inside at the center end of the seam. Arc time is 2 sec. When the weld is completed, the fixture moves the housing to the unload position where it is transferred to an inclined rack. At the end of the rack, a workman removes the small amount of spatter and loose slag and transfers the housing to a conveyor which takes it to the flange welder.

Two flange welders simultaneously join the small forged flanges, observable in Fig. 2, to the ends of the housing. An offset lap joint is made between the flanges and the housing. Flanges slide over the housing for $^3/_4$ in. Ends of the housing are formed so that the diameter at the joint is smaller than for the rest of its length. The flanges are $^1/_4$-in. thick while the housing is $^5/_{32}$ in. at the joint; the diameter is 3 in. Switching to the new welding method cut arc time to 8 sec to make the $9^1/_2$-in. long weld.

In converting previous equipment, new motor-generators with output characteristics especially suited to the process replaced former power sources. Maximum operating speed of the rotating mechanism was increased, and hoods were introduced in the arc area to protect the operator from the open arc. Otherwise the setup was identical with the submerged-arc installation.

A $31^1/_2$-in. long lap joint is employed between the dust cap and housing. The shape of the opening is "ob-round" rather than a perfect circle. A $1^1/_2$-in. joint overlap makes the total weld length 33 in. The weld joining the 0.0897-in. thick dust cap and slightly thicker housing is made in 14 sec.

Operation of the equipment in Fig. 2 is uncomplicated. Inclining the fixture base facilitates operator loading, develops better follow action in the weld crater and flattens the bead shape. The head and the hood, which covers the arc, are raised when not in use. After the operator loads the housing and its cap onto the turntable, the fixture controls actuate a pneumatic system to lower the head and hood over the work and start the arc and turntable which rotates the joint under the head. The head follows the noncircular seam through a cam arrangement on the turntable shaft that moves the head support arm in and out over the rotating housing.

Six machines are arranged in three groups of two each, on the axle housing line. Each operator runs two machines, unloading and reloading the one while the other is welding.

The new welding process has improved the quality of joints and has made a notable decrease in the number of "repairs." Porosity may, for example, be encountered on the flange joint because of unusual fit-up conditions or some foreign material in the joint. It is an easy matter to continue the weld for two revolutions to eliminate this problem and thereby ensure a pressure-tight weld. When two passes are made, speed is increased and over-all time is about the same.

Improved Hot Water Tanks

High-speed welding, without flux or separate supply of shielding gas, has brought noteworthy quality and economy to the production of glass-lined and galvanized-steel water heating tanks such as shown in Fig. 3. At State Stove and Manufacturing Co., Nashville, Tenn., longitudinal seams in the tanks are run at 175 ipm and girths at 155 ipm, speeds hitherto thought impossible.

The tanks are 13 gage steel, 14 in. in diam, and 44 in. long. Other sizes and gages also are produced

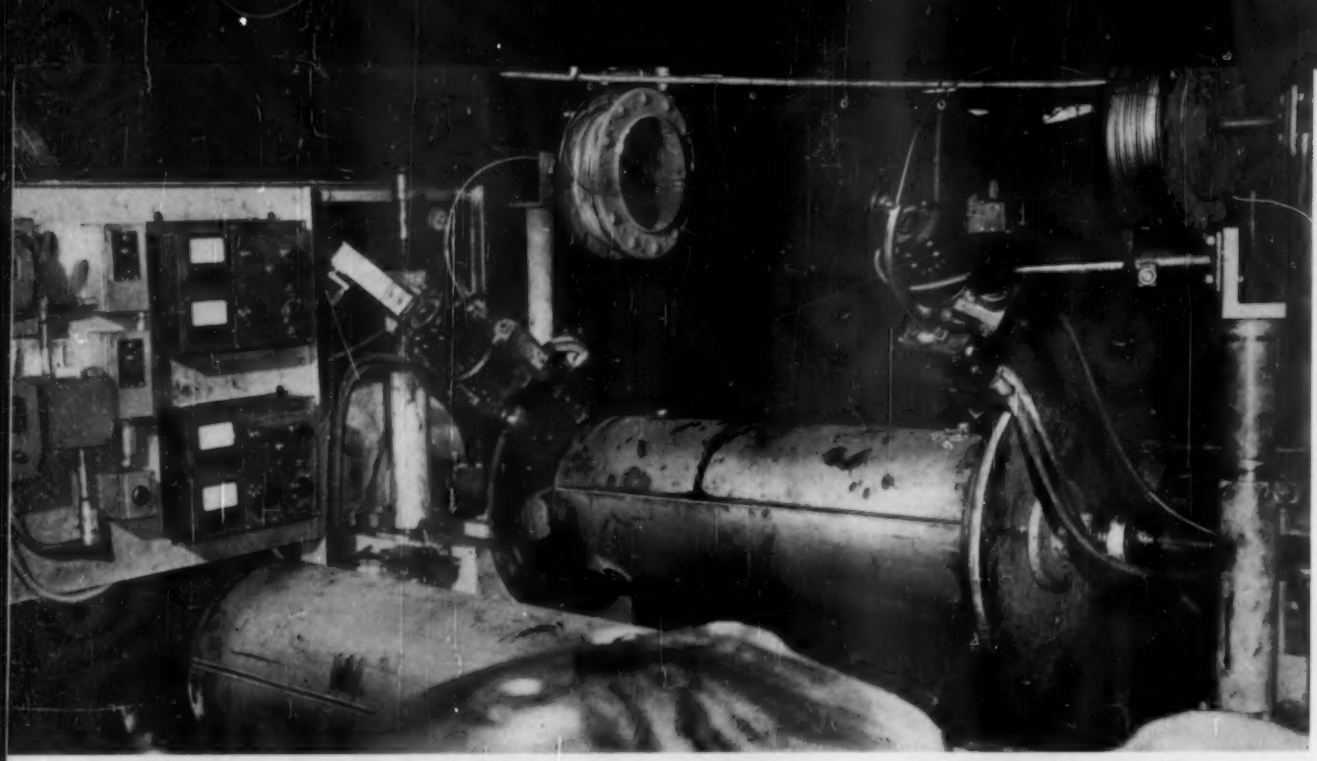

Fig. 3—Girth welding of water tank shell with welding head at 35-deg angle with horizontal and 3-in. downhill —both welds made simultaneously at 115 ipm

by the same method. The shell is first roll-formed to circular shape, tack welded, and placed on a storage conveyor. From the latter, it is raised by an air cylinder and slid over the mandrel of a special stake type fixture. The stake is inclined at 10 deg from the horizontal to give the necessary work angle, an essential of the process. The welding head, which is also installed at an extreme angle on its travel carriage, moves parallel with the work. The head is set at an angle of 35 deg to the tank axis for correct drag angle—another variable that must be controlled accurately. A convenient foot control clamps the shell in position and at the same time actuates the ground clamp, fastening it to the lower part of the far end of the shell. Grounding position also is important in the process. Welding usually progresses toward the ground, just opposite the recommended position for submerged-arc welding.

The welding cycle is fully automatic after energization through push-button controls. The current for the longitudinal seam is 950 amp at 24 arc volts, supplied by a d-c generator. A $^{5}/_{32}$-in. diam tubular electrode is used.

Full penetration of the seam is obtained on a single pass. Eliminating the flux used with the submerged-arc process results in more uniform weld contour inside and out that does not have any adhering slag, thus improving quality—especially were subsequent galvanizing is required. The smaller and more uniform bead on the shell's inner surface also requires less grinding when the tank is to be glass-lined. After the weld is completed, the inner side is given a pass with a boom-mounted grinder to ensure a perfectly smooth surface for the coating.

Another water tank manufacturer, handling 16 gage through 10 gage material, welds the seams of 16 gage shells at 200 ipm at 650 amp and 24 v. On circumferentials, 12 gage heads and bottoms are welded to the 16 gage shells at 115 ipm at 700 amp.

Structural Application

Vapor shielding also shows advantages in both speed and distortion control in the welding of lightweight beams—especially tapered beams—used in various types of prefabricated buildings made by United Steel Fabricators, Wooster, Ohio. A single head makes a flat position fillet with the beam placed in a 45-deg position. As indicated in Fig. 4, the speed of about 90 ipm is equivalent to that obtained with a tandem submerged-arc installation, yet only about half the welding equipment is required for the new process. A certain amount of rust on the plates can be tolerated without producing porosity.

Automotive Generator Frame

Electric Auto-Lite of Toledo, Ohio, uses the vapor-shielded process to make both extremely long and very short welds. Tubing for starter and generator frames is welded continuously for 74 min as illustrated in Fig. 5. A spot weld is made in 1 sec.

The housing tube is made from $^{1}/_{8}$-in. strip plate. A major saving in the method accrues from punching holes in the flat plate before forming. The punched plate is continuously formed and welded into a tube. At the end of the fabricating line, a press cuts the tubing into correct lengths for generator housings.

Units are 6–7 in. long. The welding speed is approximately 145 ipm at 750 amp and 25 v, with $^1/_8$-in. diam wire.

The inside diameter of the tube is held within 0.006 in. of dimension after cutoff, the parts are expanded an additional 0.040 in. on the diameter to ensure roundness and to avoid inside machining. After the thin tube is formed and welded, a heavy ring is slipped over it to form the magnetic iron section of the generator. The ring is about 3 in. long and is spot welded to the tube. Weld time is 1 sec. Three heads are needed to handle output of two tube mills. The spot weld is used merely to locate the ring firmly to the tube in its proper position, until the pole pieces are bolted in place.

Summary

The vapor-shielded automatic process is ideally suited to round parts that can be fabricated on a rotating positioner. Thus, opportunities are virtually unlimited. Its welding speed usually will be double that of the submerged-arc process on the same part, giving substantially reduced labor costs and a much faster turnover of production. Long, straight joints also show increased speed, partly because of less tendency to burn through.

To summarize, advantages of the process are:

1. Fast travel speeds, double those of the submerged-arc process.
2. No external flux with attendant problems of storage, reclamation and disposal.
3. No external shielding gas with concurrent demands for storage, manifolding, piping and safety.
4. Light slag, easily brushed off or left in place.
5. Over-all cleanliness, accruing from the three foregoing factors.

All of these point in the direction of production economy for welding sheet metal and light plate, the starting point of the process development. Further development now under way points to similar economy in heavier plate welding—specifically single-pass $^3/_8$-in. fillets in the horizontal position. Both full automatic and semiautomatic developments in this direction are expected to progress rapidly.

Fig. 4—Small fillets on lightweight I Beam being made at 90 ipm—section positioned at 45-deg angle to permit flat position welding and to ensure maximum welding speed

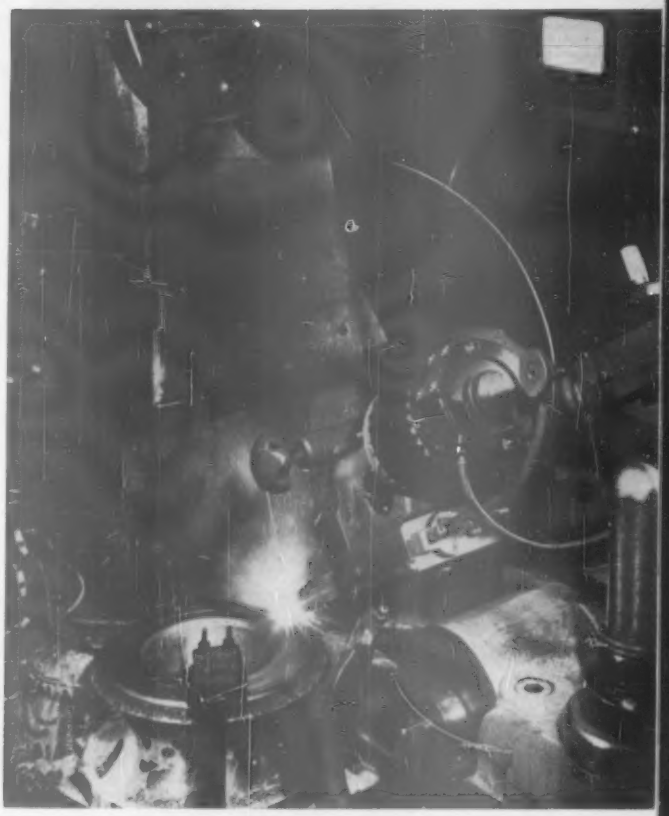

Fig. 5—Continuous welding of frames for automobile starting motors and generators—longitudinal seams have been made continuously for as long as 74 min

Welding a small hopper

Hard Surfacing of **Blast Furnace** Bells and Hoppers

is accomplished with the submerged-arc process, using iron- and nickel-base alloys

BY FRANK J. GAYDOS AND NELLO FRAGASSE

Introduction

The advent of beneficiated burdens in the blast furnace charge has accelerated wear in existing blast furnace charging facilities. The high abrasive potential of the burden—namely, taconite pellets and sintered ores—has been further aggravated by the use of increased top pressures. Another possible attack on these facilities may be corrosion resulting from the combination of hot gases and wet burden occurring in this area.

In 1958, Central Operations of the United States Steel Corp. inaugurated a project to find materials and methods for hard surfacing the principal charging components of a blast furnace top—that is, the bells and hoppers. The aim of the project was to develop some information as soon as possible, and to do so before the anticipated wear problem became serious enough to result in costly shutdown. There was very little practical information available on the selection of the best materials for use on bells and hoppers.

There were two immediate problems which required resolution in order to permit the hard surfacing of components with the size and shape of blast furnace bells and hoppers. These were the designing and procurement of the equipment necessary to handle these unusual shapes of tremendous weights and development of the technique and skill necessarily required to successfully apply the desired composition of surfacing materials selected.

Bells are large conical-shaped castings while the hoppers are cylindrical shaped castings, weighing from 40,000 to 60,000 lb each. Obviously, an experimental weld deposition on a small trial piece would not always be reproducible on a large full-sized part. The major reproducible factors under consideration were the composition, soundness and uniformity of the deposited bead—plus the absence of any checking or cracking which might result due to the expansion and contraction of the part during the welding operation.

A check-free deposit was especially desired in the seat area since it was reported that a furnace operating on a high top pressure, with a poor seal between the bell and hopper, would result in a rapid channeling wear wherever the leaks occurred. The occurrence of small checks in the burden area of the

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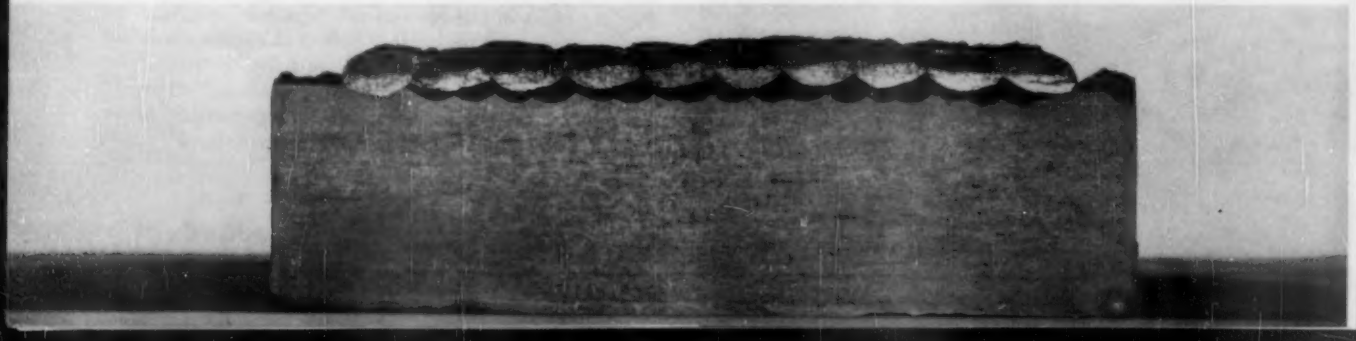
Paper presented at the AWS National Fall Meeting held in Pittsburgh, Pa., Sept. 26–29, 1960.

Fig. 1—Tungsten carbide particle insertion



parts was considered allowable, since it was felt that no channeling effect would occur there.

Material Selection

Through the combined efforts of the metallurgical and central weld departments, a search for applicable alloys was started. Numerous materials and welding techniques were employed in the preparation of trial deposits. These samples were evaluated on the basis of ease and uniformity of deposition, depth of bead penetration, soundness of deposit and bond, resistance to checking or cracking, ability to deposit in multiple layers and finally hardness of deposit.

Early experimental work included trial deposits with the insertion of tungsten carbide particles in a matrix of various hard surfacing materials. Trial deposits did not produce results considered applicable. The two major objections were the occurence of excessive thermal checks and the poor dispersion of the tungsten carbide particles throughout the deposited metal (Fig. 1). Much better control of these two factors was considered necessary before any application to a bell or hopper could be undertaken.

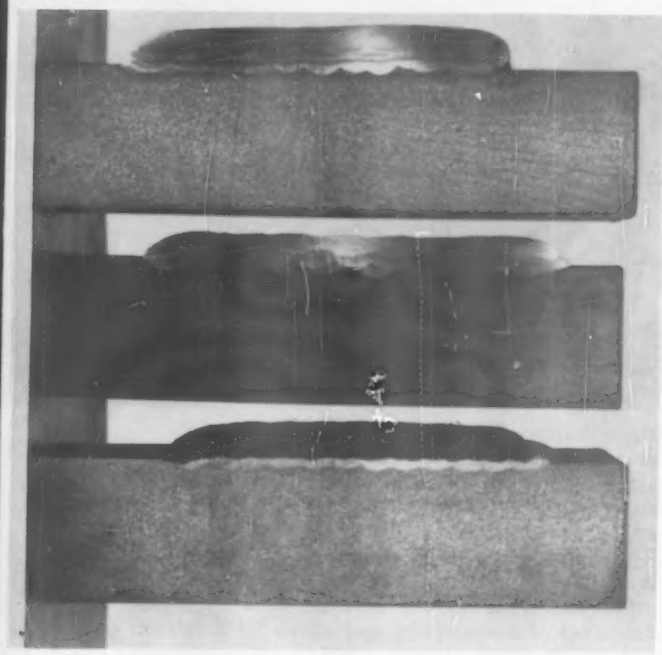


Fig. 2—5½% Ni—5½% Mo weld samples

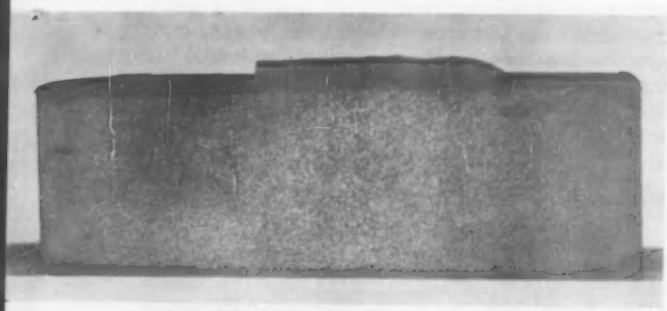


Fig. 3—16.00–18.00% Cr weld samples

After a number of trials it was decided to use iron-base alloys, except in two instances in which a nickel-base alloy was used in seat areas. The nickel-base deposits gave a readily machinable and highly polished seat area with a hardness of 27 Rockwell C. The use of this material was limited due to its high cost and its inability to resist abrasive wear as reported from experience in bell and hopper applications elsewhere.

Several applications using high carbon (2.5 to 3.0%) and high chromium (26.00 to 28.00%) were made. These applications were limited to burden areas, since it was found to check in all instances of multiple layer applications. It was believed the presence of complex chromium carbides in such a deposit would offer maximum abrasion resistance to the low type stresses anticipated in handling a predominantly sinter type burden.

The iron-based deposits standardized upon were the 8.0% chromium, 2.0% tungsten alloy for the burden area, and a 5.5% nickel and 5.5% molybdenum type for the seat (Fig. 2). Both of these alloys are martensitic as deposited, with hardness ranges of 53 to 57 Rockwell C and 40 to 44 Rockwell C, respectively. Originally only the Ni Mo type was deposited check-free, but with recent improvements in the preheating technique both types are now deposited in multiple layers check-free.

Successful applications have also been made using a 16.00% chromium and 0.50% carbon alloy (Fig. 3). This deposit is a martensitic stainless type in the hardness range of 48 to 54 Rockwell C and check-free. Additional types of hard surfacing material, including a precipitation hardening type (0.80% carbon, 9.00% nickel and 22.00% chromium) have been successfully applied on trial samples, but have not as yet been applied to large areas. In all instances it was found to be beneficial to use the maximum preheat temperatures (400 to 700° F) obtainable with existing equipment.

The bells and hoppers are cast locally from a 1030 grade of steel. All welding is done using the automatic submerged-arc method with a neutral flux.

Stress Relieving and Premachining

The "as cast" bell is given a stress relieve-anneal prior to facing. The heat treatment consists of an 1100 to 1250° F soak for a minimum of 6 hr. Following the stress relieve-anneal, the bell is positioned on a 20 ft boring mill in the central machine shop. A skin pass is made on the entire surface of the bell to be hard-faced. This area extends from just beneath the lifting lugs to the base of the seat. In the process of making the skin pass, additional metal is removed and the bell is actually trued as to

Fig. 4—Bell in position, showing spider, adaptor and shaft

Fig. 7—Stair to enclosure and work platform

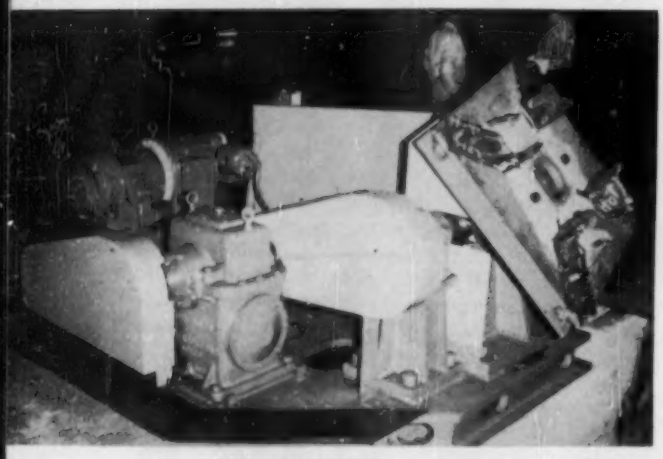


Fig. 5—Positioner headstock

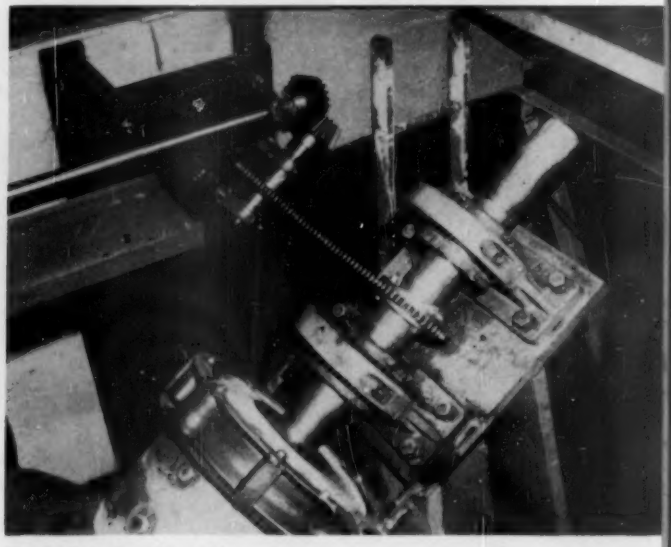
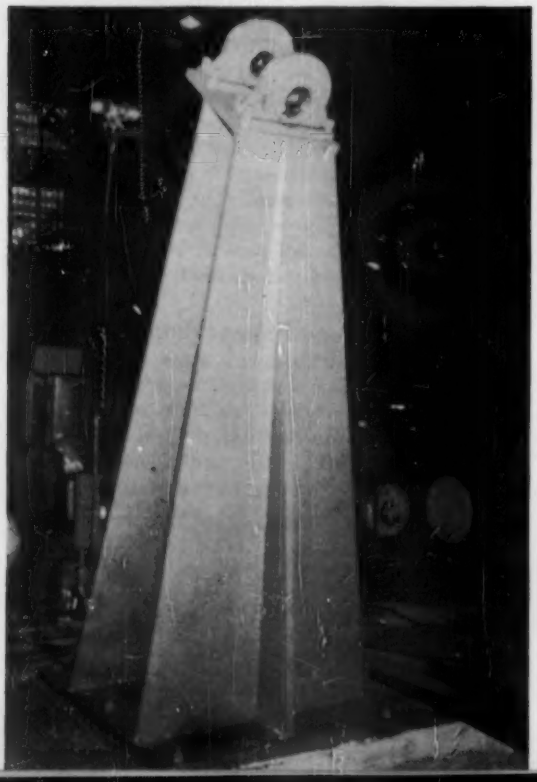


Fig. 8—Travel carriage drive—close-up

Fig. 6—Positioner tailstock



concentricity. Finally an additional $^1/_8$-in. undercut is made in the seat area (bottom 18 in. of bell). The sharp offset at the junction of the seat and burden area is feathered out over a distance of 4 in.

The undercut on the seat provides additional assurance of concentricity and allows for a layer of build-up metal should the casting contain excessive defects. It also provides for a heavier layer of hard surfacing deposit, which will compensate for the amount of metal removed in the process of finish grinding on the seat area. Finally, the premachining practice has been beneficial in revealing subsurface irregularities prior to application of the hard surfacing deposit. Such defects, unconditioned, could result in the formation of undesirable checks, breaks and cavities in the finished surface of the bell seat.

Preparation for Positioning

A special spider, consisting of four screw-adjusted jaws, is installed to the inside flange of the bell. A 4-in. diam hole that is located in the center of this spider is used to engage a matching pin on the center of the positioner turntable (Fig. 4).

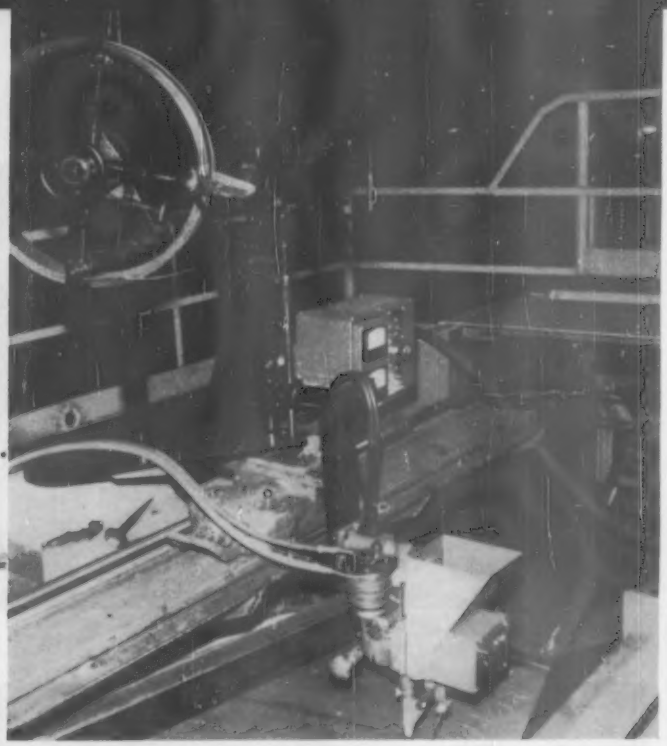


Fig. 9—Travel carriage drive

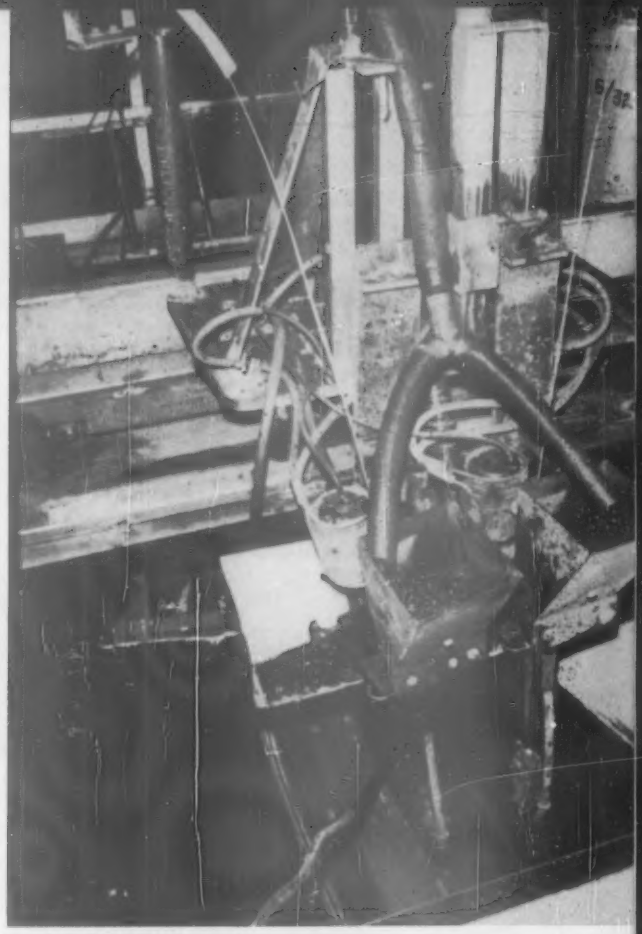


Fig. 10—Dual heads in use

At this point, a shaft or axle is installed in the bell-rod socket. On this shaft are preassembled two split roller bearings and a sprocket. This sprocket will become the driver of the lead screw that propels the welding head travel carriage. A $2^1/_2$-in. diam hole is provided through the shaft to permit the insertion of a 2-in. gas pipe. This hole is continued through the bell itself for internal heating connections.

When the bell to be hard surfaced is a "clevis-hung" type, a special adaptor is used to fit in the clevis. This permits the centering of the shaft, which is also used for the rigid type socket. Space does not allow for the drilling of a hole through the adaptor or bell; therefore, these bells are heated from the outside.

Positioner

The positioner (Fig. 5), is, in reality, a simulated head and tail stock of a lathe, set at an angle of 37 deg to the ground. When the bell is installed in this positioner its surface is parallel to the ground permitting downhand deposition of weld metal.

The headstock is driven through a series of reducers and an adjustable pulley type variable speed reducer. The reduction of speed actually used is of a 3 to 1 ratio. This represents the difference in diameters at the lug portion of the bell, where the welding starts, and the bottom of the seat area. This variable control is needed to maintain a constant peripheral speed because of the conical surface.

The tailstock is centered with the positioner table and supports the two roller bearing cages in which the shaft bearings will engage (Fig. 6). A push-button control is provided on the operator's platform to start, stop or reverse the rotation of the bell, and to control the motor operated adjustment of the variable speed control.

The Working Area

The positioner, and the working area around the bell, is enclosed on four sides and top. The purpose of this enclosure is to provide a safe working area above the bell and to maintain and retain the preheat temperatures. The top platforms on each side of the bell centerline are used to carry all the equipment necessary for the entire welding operation (Fig. 7). A flight of stairs provide safe and easy access to the working area. Crosswalks connect the two platforms.

The track and lead screw used for the welding head carriage travel are a permanent part of the platform (Fig. 8). The lead screw is driven through a pair of mitre gears, which are rotated by a roller chain drive connected to the bell shaft sprocket (Fig. 9). Each revolution of the bell advances the welding head carriage $^5/_{16}$ in.

Two welding heads are used, each being controlled separately through a control panel mounted on the platform (Fig. 10). A flux hopper is located high on the travel carriage providing flux for each head. A large auxiliary hopper containing 1000 lb of flux is located near the pickup unit for continuous supply.

Although provisions are made for the use of coil wire on the heads, 500 to 750 lb pay-off packs are used. The use of pay-off packs is time and cost saving, and minimizes material handling hazards.

Two 750-amp continuous-duty welding machines are mounted at floor level. Fans and heat shields are provided for working comfort and protection against heat.

Patching and Preheat

After the bell has been installed in the positioner, it is balanced for smooth rotation. Weights are added as needed to elimate any "jumpiness" that will affect the deposition of a continuous and smooth bead.

The patching of casting defects is done at this time. These defects are found in the form of cracks, porosity and even cavities. The defects are scarfed out and manually welded, using the proper low hydrogen electrodes. Should a defect such as a cavity be rather deep, a $^1/_2$- to $^3/_4$-in. deep bridge or a buildup is enough to prevent a submerged-arc weld "burn through."

The "clevis-hung" type of bell is heated from the outside (Fig. 11). Eight $^3/_4$-in. diam spud, inspirator burners are evenly spaced to heat the entire surface being welded; four are located on each side of the bell.

The rigid suspension type of bell is heated from the inside. A 2-in. diam pipe is inserted through the pivot shaft and a hole drilled through the top of the bell. A "christmas tree" type of burner arrangement is coupled to this supply pipe. This arrangement consists of six inspirator burners spaced 60 deg apart around the pipe and equally spaced in length. Each burner is controlled with a gate valve. Two additional burners are placed on the heavy inside flange at the seat area. The gas used is generated coke oven gas, which has a heating value of 550 Btu per cu ft.

The welding process is not started until the temperature of the bell has reached at least 400° F. Hourly readings are taken, using a contact pyrometer and temperature pencils. These readings are recorded for the study of preheat effects on the deposition of various alloys.

As the bell temperature increases, the screw-adjusted jaws of the mounting spider are regulated to allow for expansion. This procedure helps to minimize distortion since as much as 1 in. of expansion takes place during the heating cycle. This adjustment also keeps the bell centered in the positioner.

Welding Procedure

When the desired temperature has been reached, welding is started from the lug end (smallest diameter) of the bell, using the hard surfacing alloy specified for the burden area.

The two welding heads are spaced about 10 in. apart. After 10 in. have been welded, the "following head" is depositing the second pass. This pattern

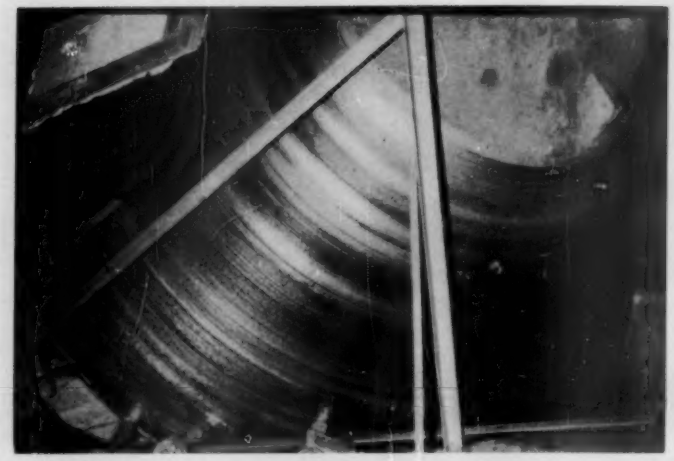


Fig. 11—Placement of burners on outside

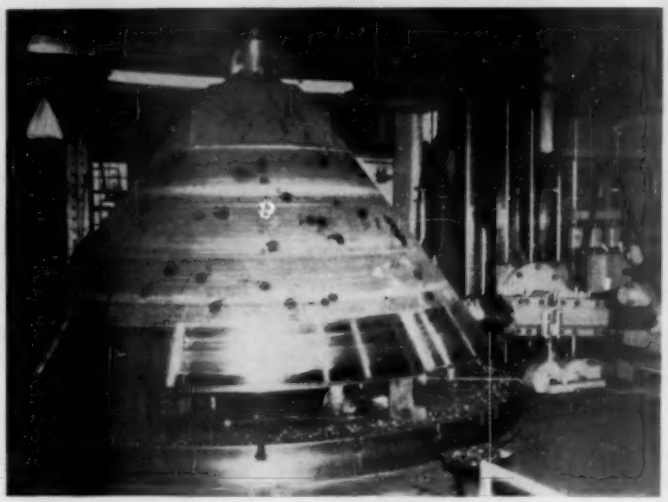


Fig. 12—Finish machining

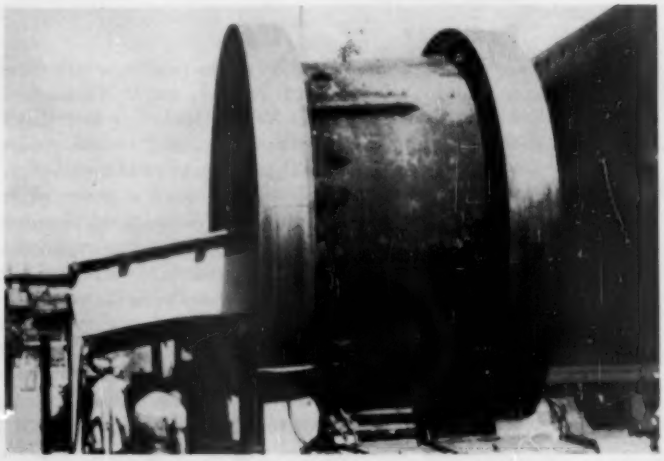


Fig. 13—Four-piece hopper welding

continues down to the start of the seat area. At this point the wire in the "leading head" is changed to an 0.08 to 0.13% carbon type. This wire will provide a build-up, alloying the 0.30 carbon seat, and will cover any defects that are apt to influence the deposit in the seat area.

When the "following head" reaches the seat area, its wire is changed to that of the seat alloy. With one more run across the seat area with both heads using the seat alloy, the welding job is completed. The seat area deposit now consists of one build-up layer and three layers of seat alloy.

Using this sequence of welding, the burden area is covered with two passes of surfacing averaging $^{5}/_{16}$ in. in thickness. The seat area has four passes measuring a $^{1}/_{2}$-in. plus in thickness.

During the welding cycle, the temperature of the bell may reach as high as 700° F. This is very desirable to prevent checking. The procedure of depositing one layer on top of the other in close sequence has helped to raise this temperature. The slow cooling gradient has proved very beneficial in reducing checking in alloys of high Rockwell hardnesses.

Welding speeds vary from 23 to 30 ipm. The amperage range is from 450 to 600 amp. Deposition rate varies from 18 to 26 lb per head per hour, depending on whether it is the "leading" or the "following head." Preheat, welding and slow cooling operations progress on an around-the-clock basis until the job is completed.

Slow Cooling and Machining

With the completion of welding, the bell is allowed to rotate with all burners in use. Gradually the burners are moved back and finally withdrawn. When burners are located inside the bell, the valves controlling them are adjusted; finally one by one they are extinguished. All these movements are made to allow for a maximum temperature drop of 25° F per hr. The bell is cooled to room temperature, being rotated during the entire cooling cycle. During the cooling cycle, the spider dogs are loosened to allow for the contraction of bell as it cools.

From the weld shop, the bell is moved to the machine shop and positioned on the 20 ft boring mill (Fig. 12). Machining at this stage consists of cleaning up the seat area (bottom 18 in. of bell). A carbide tipped cutting tool attached to a specially designed ram is used to clean up the seat area, which is afterwards ground to a mirror-like finish. In some instances, due to the smoothness and uniformity of the deposited metal, it is only necessary to resort to a grinding operation in finishing the seat area. Distortion of the bell due to welding operations has been held to a maximum of $^{1}/_{8}$ in.

Hopper Examples

Welding procedures and materials used for hard surfacing the large bell are also used to surface the large hopper, the small bell and the revolving distributor hopper. Experience in the welding of hoppers was developed on a four-piece bolted job for a 15-ft bell (Fig. 13).

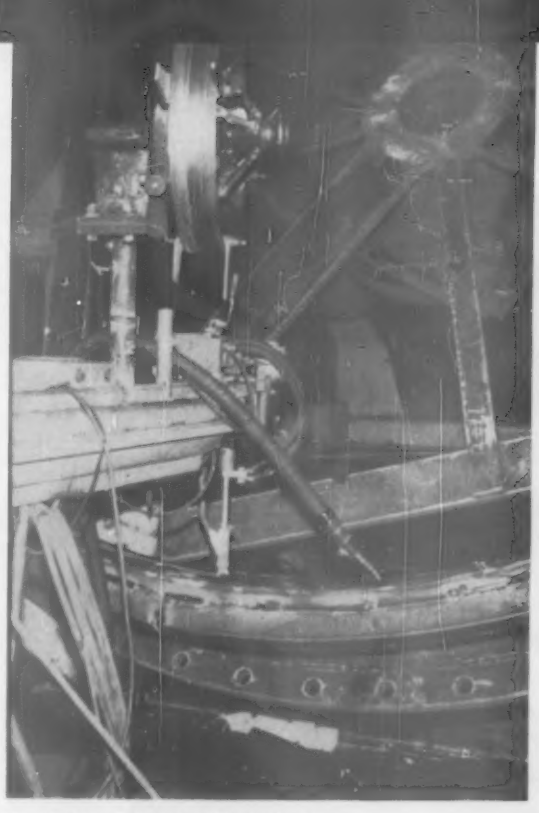


Fig. 14—Hopper ring welding setup

It was found, by inspection of several hoppers, that the maximum wear occurs in an area 30 in. above the bottom or seat. It was therefore, felt that a 36-in. high deposit should be sufficient for the hopper wear surface.

A multiple section hopper presents a peculiar distortion problem due to welding heats. The bolting flanges are much heavier in section than the shell. Uneven heating results, and the thinner shell cools faster than the flanges; this distorts the seat area into a modified "four-leaf clover" shape. To combat this, preheats are lowered and an extra heavy deposit is made on the seat to restore it to roundness. Wide bands are fastened to the top flange and near the seat area, providing the hoops necessary to revolve the hopper on motor driven rollers for the welding operation.

Where blast furnace top rigging allows, two piece hoppers are used. This type of a hopper is desirable when high top pressures are used, since flange connections in the vertical plane, have a tendency to open up allowing gas "blow-by." Inasmuch as the lower 30 in. or so receive the greatest wear, the possibility of salvaging the upper portion is being explored. The hopper is divided into two parts circumferentially, the lower portion being 36 in. high. A recessed flange connection is provided to connect the two parts.

The hopper ring is premachined in the seat area and up the inside surface about 6 in. (Fig. 14). One heavy layer of hard surfacing material is applied from

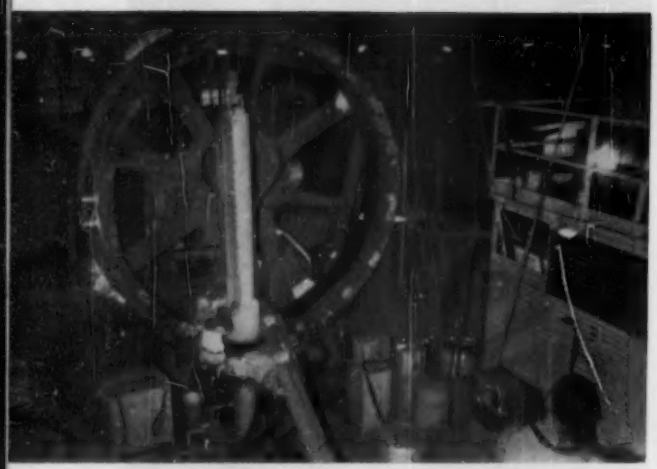


Fig. 15—Hopper ring welding setup

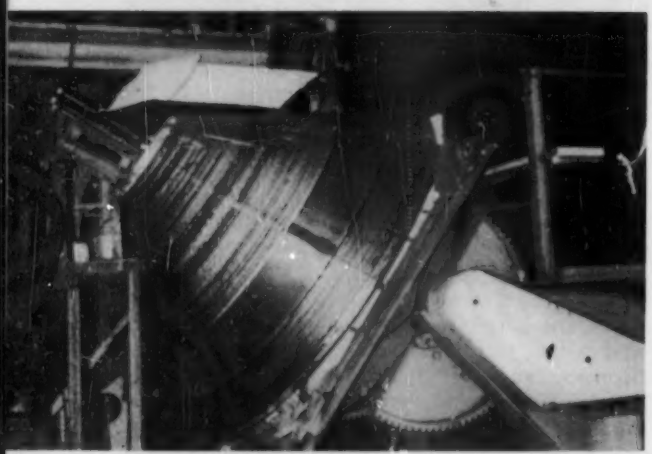
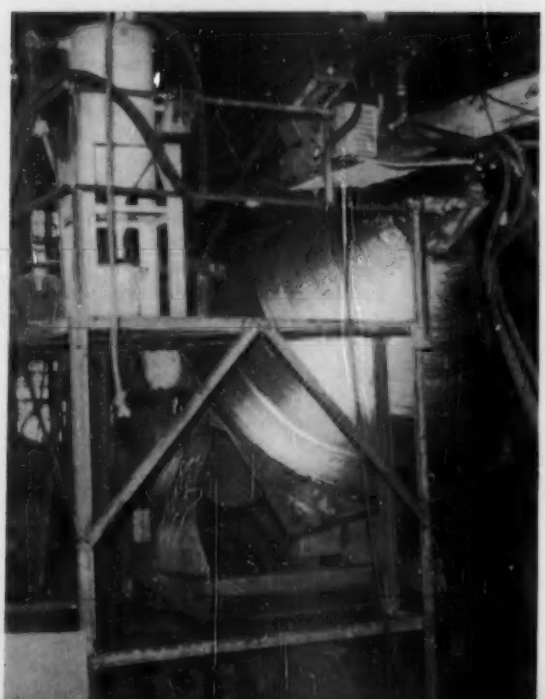


Fig. 16—Close-up of small bell welding



2 in. above the seat to the flange. The seat material is applied in $^5/_8$ to $^3/_4$ in. thicknesses to provide ample clean-up tolerance (Fig. 15).

Preheat to a hopper is applied from the outside, using two burners on each side of centerline. The preheat temperature is lower and averages 300° F. Since a hopper resembles a very large hoop, excessive heat would tend to aggravate distortion of this shape even though it is mounted on a cross braced spider.

Small Bells and Hoppers

A small bell is probably the hardest working element of a blast furnace's charging mechanism. The skip car dumps its burden onto the small bell which, in turn, delivers this burden to the large bell. The frequency of material sliding over the surface of the small bell is considerably greater than that of the large bell. Although the changing of a small bell does not present too great a problem, extended life is desirable for continuous operation, efficiency of the top seal and safety of workers who may be involved in the change.

A small bell is a two-piece casting connected by bolted flanges on the inside of the bell. The flanges are machined as well as drilled, and the bell is assembled. A skin cut is taken off the entire surface, and the seat area is undercut an additional $^1/_8$ in. for added build-up. After machining, an $^1/_8$-in. wide copper strip is inserted between the flanges (Fig. 16). The strip is kept below the surface for insertion of carbon paste. This preparation allows for a cleavage line to separate the halves for final machining and assembly in field.

The bottom of the bell is cross-braced from flange to flange. It is imperative to install one of these braces to the flanges directly or else distortion will occur. The holes that are provided for eyebolts used to handle the bell halves are likewise filled with a carbon round and paste to prevent filling with surfacing material (Fig. 17).

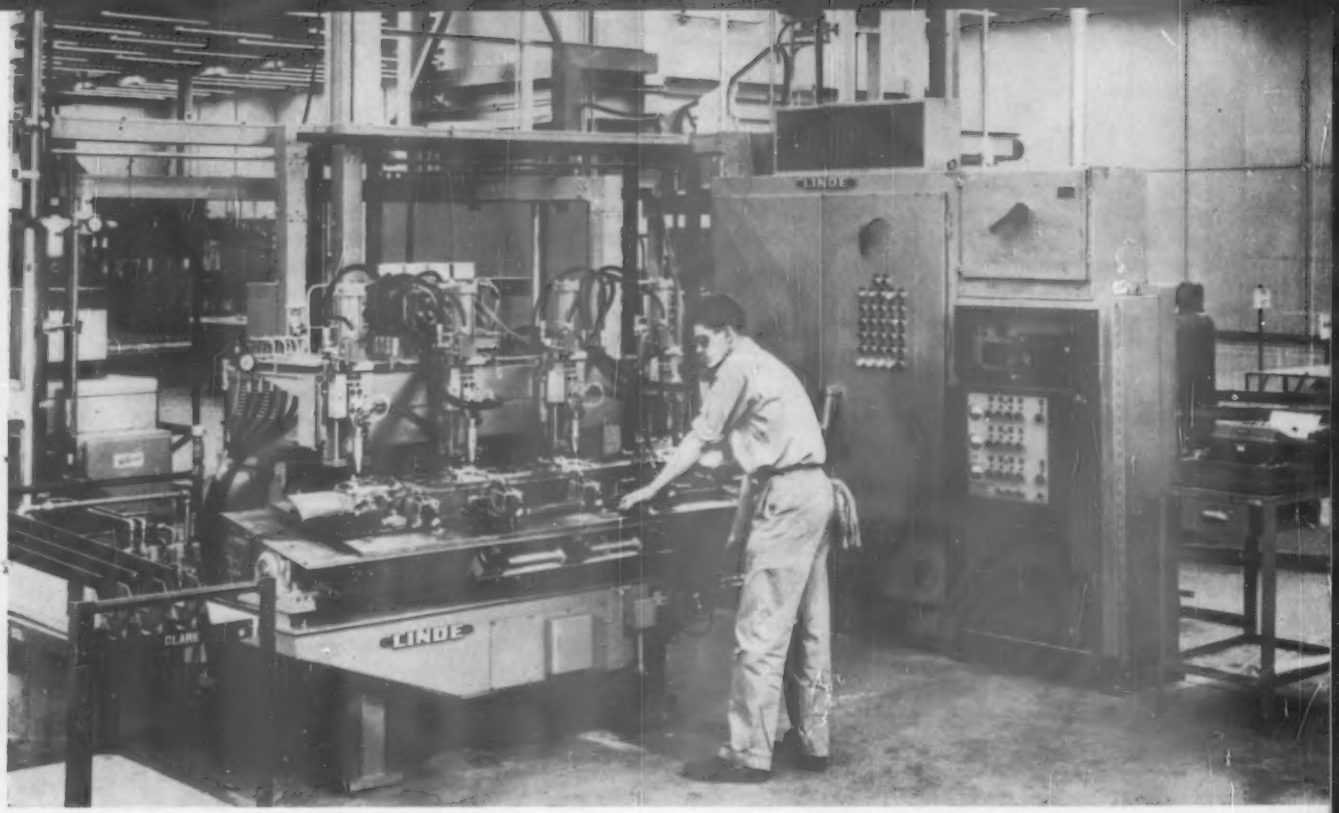
After mounting on a special base plate attached to a standard welding positioner, three burners are inserted inside the bell. A preheat of about 500° F is maintained throughout the welding cycle.

The small bell hopper is welded on the inside for its entire length (lead photograph). The manipulation of the hopper is dependent upon its weight, which determines the use of the standard welding positioner or power driven rollers.

Conclusion

This is a résumé of materials, equipment and methods now being used at Gary Steel Works. These were devised to get an urgent wear problem under control as quickly as possible. Others have designed special equipment to handle the massive pieces that are involved. The use of materials has varied, and new compositions are being developed. The final answer to the life of any material may be long in coming to light—especially if the right materials and techniques were selected for application.

Fig. 17—Small bell welding setup



Application of tape-control programmed tungsten-arc spot-welding machine for production of missile fins

Inert-Gas Spot Welding in the **Aircraft and Missile** Industry

proves a valuable production tool for fabricating structures from high-tensile heat-treatable steels. Process features are simplicity of application, flexibility and reliability

BY R. L. HACKMAN

Introduction

The task of aircraft and missile manufacturers is to meet the challenge of tomorrow. In doing so, however, the fabrication problems of today must first be solved. Such problems are arising almost daily. They do not involve advanced techniques of weapons system analysis; they do not involve detailed computations concerning the geometry of inertial forces for the earth, moon and synodic satellites. Instead, they are much simpler—deceptively so. Even though they appear simpler, however, they are nonetheless pressing and frequently require an immediate solution.

Specifically, concern here is with the fabrication of high-strength low-weight ratio structures fabricated from high-tensile heat-treatable steels such as 17–7 PH, 15–7 Mo. The problem has been to develop suitable inert-gas spot-welding techniques to fabricate assemblies from these materials. In this respect, considerable progress has been made by various aircraft and missile component fabricators in the application of inert-gas spot-welding to the high-tensile strength steels—particularly the tungsten-arc process in that the consumable electrode process produces spot welds which, for the purpose of aircraft and missile fabricators, have too high a

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degree of nugget reinforcement and generally a lower degree of reliability.

In most cases, the information developed by a given manufacturer has been for a specific application. Since this type of information has been developed at many locations, the details of no one application present a complete story. Therefore, a purpose of this paper is to bring together much of this information and to couple it with the results of the original laboratory development.

Nature of Tungsten-arc Process

The Welding Operation

Tungsten-arc spot welding is a process wherein an electric arc is struck in an inert-gas atmosphere between the workpiece and a torch electrode, which usually is thoriated tungsten (Fig. 1). The heat of the arc causes a weld puddle or nugget to form with extreme rapidity. The process has several inherent advantages, which are principally as follows:

1. Welds can be made from one side of the work. Thus, only one side of the joint need be accessible.
2. There is no practical restriction on thickness ratio of sheets to be welded when joining thin to thicker sheets. In the case of the reverse combination of thick to thin, there is reasonably good latitude as also exists when joining pileups of three thicknesses.
3. Shunting is not encountered, and therefore the center-to-center distance between spot welds is limited only by the heat-affected zones.
4. The surface resistance of the parts, particularly the faying surfaces, is not as critical as with other processes.
5. The completed welds are clean, strong, uniform and predictable; after-cleaning or other operations are generally not necessary.

Starting Methods

Instantaneous ignition of the welding arc is necessary to obtain the consistent results required in spot-welding operations involving aircraft and missile materials. To this end pilot-arc starting is used. This method of starting is accomplished through a small arc of about 1 to 5 amp continuously maintained between the torch nozzle and the welding electrode. The pilot arc keeps the electrode hot and the shielding gas ionized, thereby ensuring positive starting of the main arc. A typical circuit is shown in Fig. 2.

The process of spot welding with pilot-arc starting represents a great improvement over the previous methods of spot welding, using conventional high-frequency or retract starting. Pilot-arc starting has several distinctive features:

1. One hundred percent positive starting can be obtained so long as the pilot arc remains ignited, regardless of the welding current setting from 1 amp up to the desired value. By contrast, low-current starting with high-frequency or retract starting is unreliable, particularly when the end of the electrode is blunted to obtain best results on many high-alloy steels.
2. The pilot arc maintains the thoriated tungsten electrode in a state of incandescence and thus represents a nonvariable operating factor. In addition, there is no need to make a few preliminary spots on a scrap piece to bring the electrode to the proper temperature. Thus, all spot welds can be of equal quality. There is no such thing as a cold spot weld.
3. The postheat effect of the pilot arc is beneficial in reducing or eliminating crater cracking.

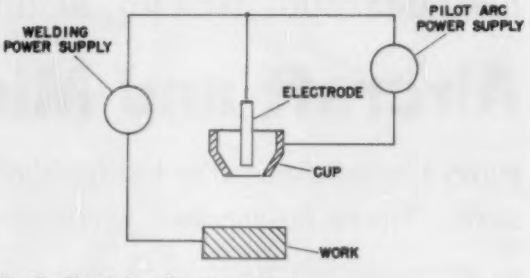


Fig. 2—Circuit for pilot-arc starting

Fig. 1—Process schematic for tungsten-arc spot welding

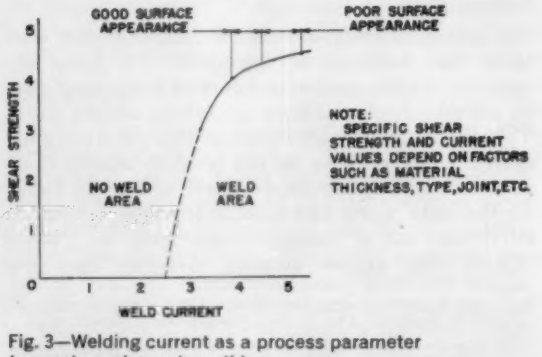

GOOD SURFACE APPEARANCE
POOR SURFACE APPEARANCE
SHEAR STRENGTH
NO WELD AREA
WELD AREA
NOTE: SPECIFIC SHEAR STRENGTH AND CURRENT VALUES DEPEND ON FACTORS SUCH AS MATERIAL THICKNESS, TYPE, JOINT, ETC.
WELD CURRENT

Fig. 3—Welding current as a process parameter (current vs. shear strength)

Analysis of Process Parameters

Limitations of Past Knowledge

Most users of the tungsten-arc spot-welding process probably recognize current, arc length or voltage, welding time and electrode shape as process parameters. However, the degree to which the interrelationships of these parameters has been recognized is questionable. Further, not much is known of how a particular parameter varied over the extremes of its possible range can produce widely varied results of a highly nonlinear type. Generally, it has been recognized that current is a relatively insensitive parameter while arc length is somewhat more sensitive and time is extremely sensitive. To some extent, the importance of electrode shape has been recognized. Probably, however, most users would select a pointed 0.040-in. diam electrode when joining 0.010- to 0.005-in. thick stainless steel. Actually, experience indicates that a $^1/_8$-in. diam electrode brought almost to a point will do a somewhat better job.

Analytical Approach

Tungsten-arc spot-welding parameters are analogous to dependent and independent variables in an equation. Therefore, to determine their effect and magnitude, one must in effect determine experimentally a vast number of combinations which can then be set up for solution as a series of simultaneous equations. To attempt to portray this type of analysis graphically would be impossible, since more than three dimensions are involved. Therefore, as a rule, the parameters are paired off to determine interrelationships between particular pairs. The effects of current, time, arc length, and—to a lesser degree—electrode shape on weld results are then measured by consistency, shear strength and surface indentation.

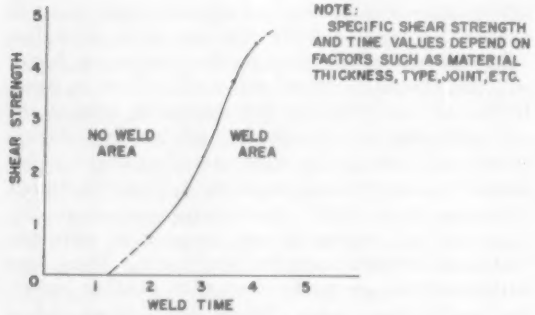


Fig. 4—Weld time as a process parameter (cycles vs. shear strength)

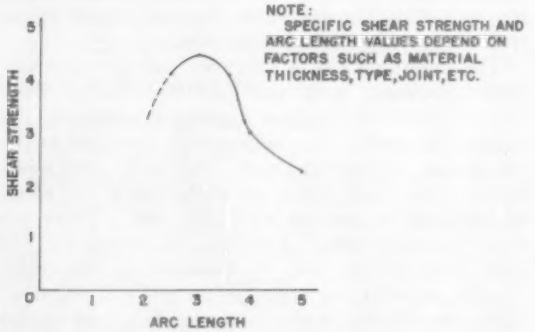


Fig. 5—Arc length as a process parameter (arc length vs. shear strength)

Specific Variables

Current. In considering welding current as a parameter, examination of Fig. 3 will show that, over a considerable range of welding current, the shear strength can only be expected to increase by approximately 30%. Furthermore, the last increments of this increase will be accomplished with the penalty of extremely poor surface conditions. The current parameter curve relative to shear strength is relatively flat in the usable range, exhibiting no tendency to an inflection. On the other hand, however, the slope of the curve becomes steeper as the material being joined becomes thinner. The shape, however, does not change particularly with changes in thickness, nor generally with changes in steel analyses. It will be shown later that current can be varied over a rather large range with satisfactory results. However, other parameter values will then depart considerably from their optimums, and their adjustment may become quite critical.

Welding Time. Figure 4 shows the effect of the welding time parameter on shear strength, which is shown to the same scale used in Fig. 3. Immediately it becomes evident that changes in time have considerably more effect on shear strength than does current.

The somewhat "S" shape of the time curve relative to shear strength shows that, for the first part of the welding cycle, most of the heat spreads throughout the weld zone and brings the material up to its fusion point. Then, during the latter part of the weld cycle after fusion temperature has been reached, small increases in time can account for considerable increases in shear strength and penetration. Thus, a 20% decrease in welding time could conceivably account for as much as a 100% or more decrease in shear strength. Relating time to current, it becomes obvious that, for a given shear strength, the current should decrease if time increases.

As is the case with the current, we would expect the curve in Fig. 4 to become steeper as the thickness of materials to be joined decreases. In this event, the time curve would be considerably more vertical. Thus when welding materials in the 0.005- to 0.010-in. thickness range, a difference of 3 or 4 cycles will have a very large effect on the resulting shear strength.

Arc Length. The effect of arc length on shear

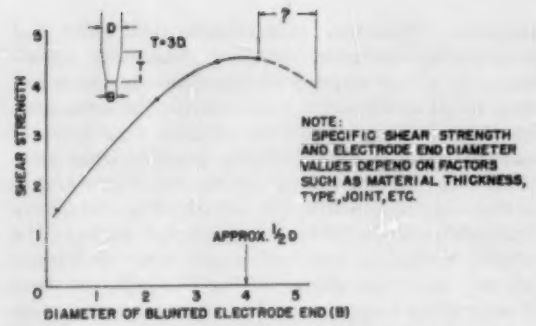

SHEAR STRENGTH
DIAMETER OF BLUNTED ELECTRODE END (B)
T=3D
NOTE:
SPECIFIC SHEAR STRENGTH AND ELECTRODE END DIAMETER VALUES DEPEND ON FACTORS SUCH AS MATERIAL THICKNESS, TYPE, JOINT, ETC.
APPROX. ½D

Fig. 6—Electrode shape as a process parameter (blunt-end electrode diameter vs. shear strength)

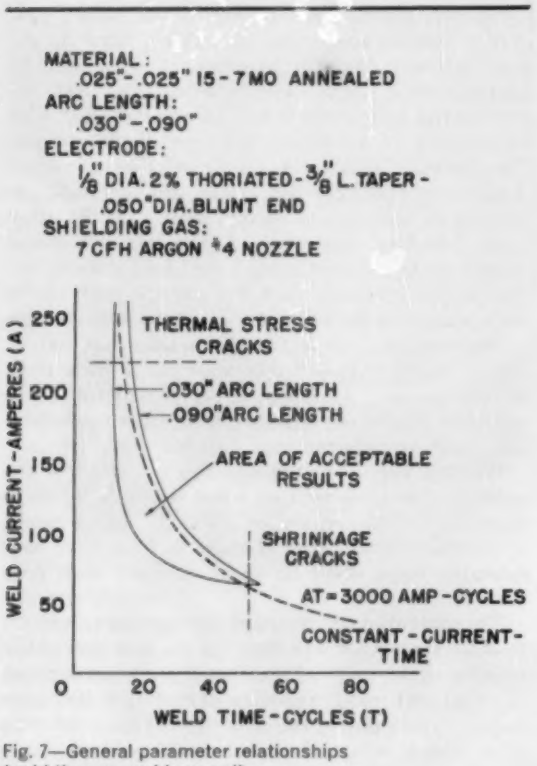


Fig. 7—General parameter relationships (weld time vs. weld current)

strength at a given current and time is shown by Fig. 5. As indicated, shear strength is increased with increasing arc length until a maximum is reached after which further increases in arc length will cause a decrease in shear strength. Obviously, then, selection of the proper arc length for a given application is extremely important. However, the top of the curve on either side of the maximum point is relatively broad and, thus, an arc length variation of ±0.005 in. will not greatly affect the resulting shear strength.

Analysis of Fig. 5 suggests that, at very short arc lengths, the arc is highly concentrated and therefore tends to form a deep narrow penetration. As arc length increases, penetration is broadened and thereby widens the diameter of the nugget at the faying surface. This continues until a point is reached where additional increases in arc length result in a loss of arc melting efficiency wherein much of the heat is now spread superficially along the top of the upper sheet. Thus further increases in shear strength cannot be expected, and shear strength in fact falls off. The shape of the curve in Fig. 5 and the arc length point where maximum shear strength is found will be effected to some extent by the shape of the electrode end.

Electrode Shape. Two factors are important when considering the shape of the electrode—electrode taper and the diameter of the electrode tip. If taper occurs over approximately 3 diam of the electrode, this factor can generally be dismissed from further consideration. Thus the only factor under discussion becomes the tip of the electrode—that is, whether it is pointed or whether it has been blunted and to what degree.

Figure 6 shows the effect of blunting the electrode on shear strength. As mentioned previously, there is a relationship between the diameter of the blunted end of the electrode and arc length. Thus, the curve in Fig 6 is similar to the arc length curve of Fig. 5. However, in Fig. 6, the curve is shown going only up to about its maximum, while further extension of the curve in terms of a larger blunt area will probably show a definite decrease in shear value.

In the case of arc length, the important factor was the effectiveness or ability of the arc in penetrating the upper sheet, the impinging area of the arc increasing with increasing arc length. Here a similar phenomenon is encountered in that current density at the tip changes as the degree of electrode bluntness is changed. Decreasing current density increases the impinging area through an optimum just as does lengthening the arc length. Thus, heat can be introduced to the sheet with another control on impingement area. When the blunted end of the electrode becomes too large, the result is essentially the same as excessively long arc length. The power of the arc is now widely spread over the top surface of the sheet but exhibits little penetrating characteristic. Thus, excessively large surfaces are melted on the top sheet with very little penetration through the faying surface.

The importance of a blunt vs. pointed electrode shape increases with electrode size, being most significant on $^1/_8$-in. diam electrodes nominally the largest size used. The information described in the preceeding paragraph was, therefore, developed solely with $^1/_8$-in. diam electrodes since the effect of blunting is greatest with this size. There are other considerations, however, in examining the effect only on this size. It appears that, regardless of the material thickness to be welded, equal or better results can be obtained with $^1/_8$-in. electrodes combined with pilot-arc starting than with any smaller size. From a mechanical standpoint, elec-

trode eccentricity is minimized, electrode life is greater, and as a result end dressing and gap adjustment of the electrode are reduced. As mentioned earlier, better results have been produced with blunted 1/8-in. diam electrodes than with 0.040-in. diam electrodes when joining 0.010- to 0.005-in. thick stainless steel. Similar results may not be obtainable when using HF or retract starting since these starting methods do not perform well with blunt electrodes.

General Relationships

An experimental welding program was conducted to define the relationship between time and current as it affects the consistency, indentation, cracking, and shear strength of spot welds. In this case, the material welded was 15–7 Mo (Condition A). The top and lower sheets were both 0.025 in. thick. A 1/8-in. diam, 2% thoriated tungsten electrode was used with a 0.050-in. diam blunt end and a 3/8-in. long taper. In order to be acceptable, it was necessary for any group of three welds to exhibit an average strength of 655 lb. Furthermore, indentation could not exceed 0.006 in. and consistency (computed in terms of percent variation*) could not exceed a variation of 10%. In addition, cracking of the weld could not exceed 25% of the weld diameter nor occur within 25% of the boundary. Likewise, internal defects could not occur or extend more than 25% into the top sheet and not extend within 15% of the nugget boundary. Cold wire addition, which can greatly reduce or eliminate cracking, was not used since this additional element would further complicate the problem without adding to its understanding.

The results of the investigation are depicted by the area enclosed by the two curves in Fig. 7 illustrating the upper and lower limits of time and welding current combinations which produced acceptable welds. It can be seen that, for the most of the area, time could not vary too widely, while relatively wide variations in welding current were permissible. At the extreme right limit of the area, considerable variation in time could produce satisfactory results although current settings became extremely critical at these points. At both ends of the area, cracking developed. Thus, the extremities of the enclosed area do not represent practical operating conditions. It is interesting to note that a constant current-time curve can be plotted through the defined area.

Results of Mechanization

Manual Vs. Mechanized Spot-Welding

When comparing manual and mechanized spot-welding, the thickness of the material involved must first be considered. If the material is not very thin and a good forming job has been done so that finger pressure will bring the faying surfaces together, then the amount of torch pressure applied in the case of a manual application is not particularly critical. Thus, with a manual torch the results would be no different than if a mechanized torch were used. However, when considering materials which are 0.010-in. thick or less, torch pressure becomes a consideration—not as a means to bring the sheets or faying surfaces together but rather in terms of the amount of distortion that could be introduced from excessive pressure. In this case, use of a manual torch could be objectionable whereas, with recently developed mechanized equipment, it is now possible to exert pressures as small as 16 oz consistently in continuous spot-welding operations.

A second consideration when comparing manual and mechanized tungsten-arc spot welding is location accuracy of the spot weld. Obviously in manual applications, this is limited to such visual guides as are available to the operator and his ability to line up on them. Furthermore, in the case of thin vs. thick materials, another consideration is the preheat effect of the pilot arc. In the case of a relatively thick section, the preheat normally encountered in locating the manual torch would not constitute a consideration. Even with a 1 amp pilot arc on thin sections, the amount of preheat introduced could become quite significant if the operator dwelt in the immediate area for some time trying to determine whether he was properly lined up. Again in the case of structures such as corrugated or waffle cores, the land or flat generally provided on the undersheet is quite small. Thus, even with a template or guide for the manual operator, location accuracy becomes a difficult problem. With mechanized installations on the other hand, location accuracy is taken care of very simply through either adequate fixturing to index the part under the torch or by indexing the torch over the work.

Mechanized Spot-welding

At present there are four varieties of tungsten-arc spot welders. The first and most widely used is the manual gun which has been known to industry for approximately 10 yr. More recently three mechanized varieties have appeared. Chronologically, the first was used in the manufacture of the torus assemblies for automotive transmissions and could be classified as a cluster arrangement in which as many as six torches were indexed in a common holder.† In other words, the torches could not be moved in or out individually. The second variety, also a multiple torch welder, is the tape-control programmed spot-welding machine. Such a unit was installed approximately two years ago for the manufacture of missile fins. In this case, the machine was equipped with four torches which could be operated independently but were positioned as a group. Last and most recent, has been the single-point welder which, as the name implies, has a single torch mounted on a suitable arm or support mechanism with the work generally being indexed under the torch.

* Percent variation = range of shear values/mean shear value × 100.

† Mertens, W. G., and Ryder, O. J., "Inert-Gas Tungsten-Arc Spot-Welding of an Automotive Transmission Sub-Assembly," The Welding Journal, 36 (9), 871–76 (1957).

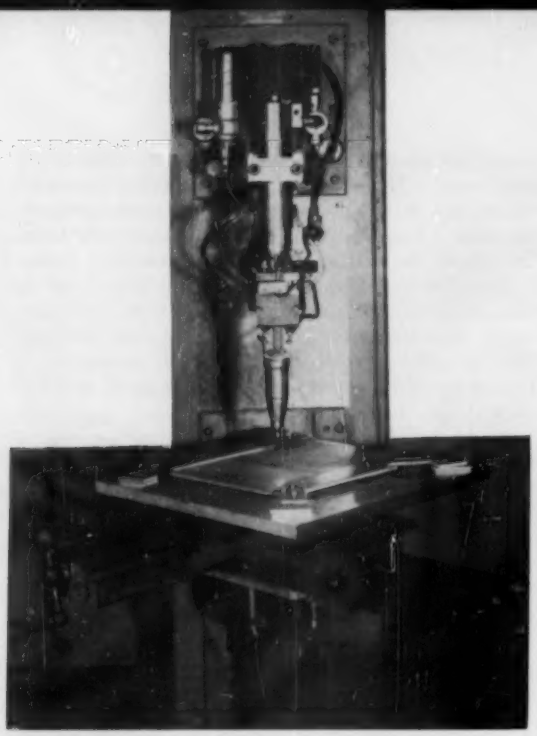
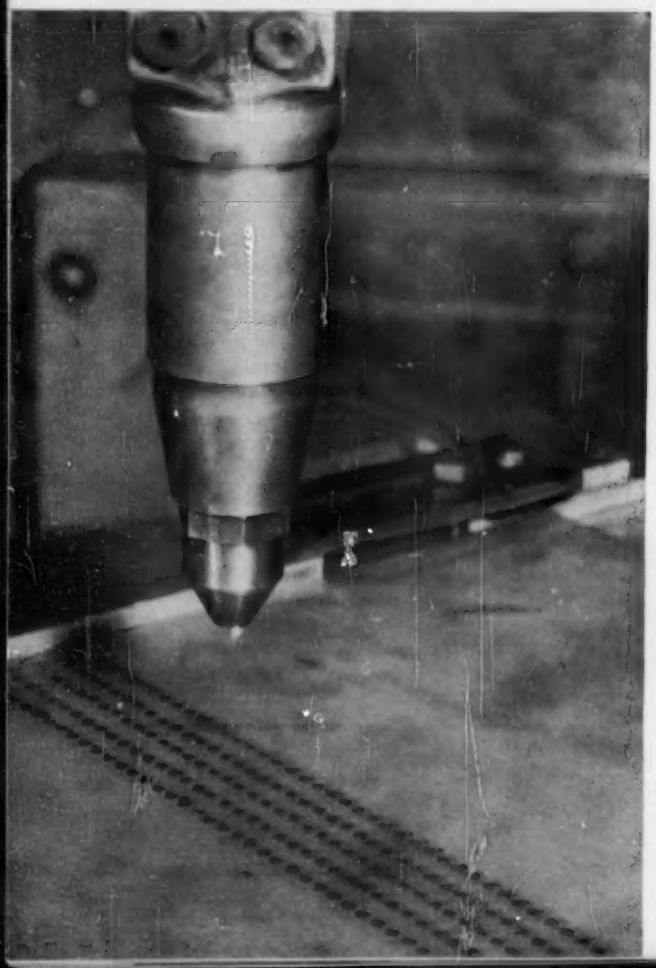


Fig. 8—Single-point tungsten-arc spot-welding machine—torch actuating mechanism

Fig. 9—Single-point tungsten-arc spot-welding machine—close-up of torch over work (note pilot-arc in torch and 5 rows of completed spot welds)



The single-point welder, as illustrated in Fig. 8, is particularly adapted to the fabrication of corrugated or waffle core structures as well as other aircraft or missile assemblies where extremely thin gage steel members are to be joined together. This machine incorporates a balanced air system in which a fixed air pressure is maintained on either side of the piston which raises and lowers the torch. This provides a rough control over speed and, in the case of applications requiring 10 lb or more pressure, the differential between the two determines the exact pressure applied.

In applications requiring less than 10 lb pressure, an additional element is incorporated to sense the reactive force of the torch coming in contact with the work. As previously stated, this can be set to pressures as low as 16 oz. In experimental work, pressures half of this have been consistently achieved but it is questionable whether a force of approximately 8 oz has any practical value. Although a matter only of fixturing expediency, this particular machine is equipped with a pair of 30-in. cross slides with a thread pitch of 10 to the inch. For most current applications of tungsten-arc spot welding to thin stainless aircraft and missile structures, this arrangement is quite suitable for development and semi-production applications. Obviously the cross slides could have a programming device attached to elimi-

① SPOT WELD JOINING SKIN, DIAPHRAGM, AND FORGING

② SPOT WELD JOINING SKIN AND DIAPHRAGM

③ SPOT WELD JOINING SKIN TO SKIN

Fig. 10—Cross section of control fin

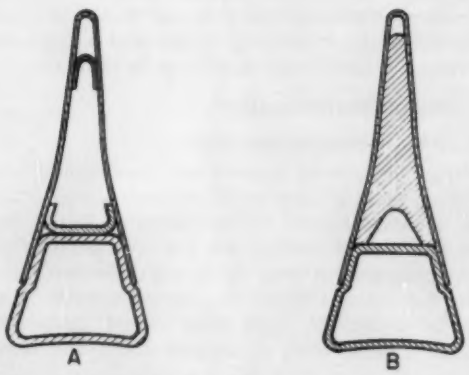


Fig. 11—Two cross sections of dorsal fin

nate any manual function in the over-all operation. At present, when turning the lead screws manually, spot welds can be put in at a rate slightly in excess of 1 spot per sec.

Figure 9 shows a close-up of the same machine with an assembly which has already been partially welded. To perform this operation the operator merely sets the machine for an automatic repeat speed slightly less than his ability to turn the lead screw and advance the work. It might be compared to a sewing machine wherein the length of the stitch depends on the rate at which the material is fed under it. Panels produced with this machine have been surprisingly free of distortion.

Tape-control Programmed Operations

The lead photograph illustrates a tape-control programmed tungsten-arc spot-welding machine, which was installed two years ago for the completely automated fabrication of missile fins. This unit is completely automatic and, with changes in fixturing, can handle a variety of parts. This eliminates the need for separate welding machines to handle different type parts, thereby reducing equipment and floor space requirements.

The machine as shown occupies an area which is approximately 25 ft sq. It consists of two major components—the controls and the basic machine.

The controls consist of three interlocked sections. The first is a tape control which serves as the brain of the machine. The other two are the mechanical and welding controls. The purpose of the tape control is to interpret a punch tape, which is prepared on a Flexowriter typewriter prior to the welding operation. As the tape control reads the tape, it immediately activates operation of the basic machine with respect to machine positioning and selection of the welding conditions. The mechanical control does such things as monitor the fixture clamping and parts location accuracy. It also controls the cooling water flow and argon pressure. The welding control directs the torch slide operation and times the weld cycle and post hold.

The basic machine includes four tungsten-arc spot-welding torches. Based on information transmitted by the tape control, slides automatically position the torches as desired over the parts being welded while a work platen automatically tilts the parts so that the torches are always perpendicular to the work during subsequent welding. Four 300-amp power supplies are used, one for each torch. Argon is supplied at a rate of 7 cfh per torch. Arc ignition is accomplished with pilot-arc starting.

The tape-control programmed spot-welding machine is now being used to spot weld two missile fins. These are the control and the dorsal fins. Figure 10 shows a bottom view of the control fin where three different types of spot welds are made. Weld No. 1 is a joint wherein the 0.025-in. thick skin and the 0.016-in. diaphragm section are joined to a heavy forged spar which, in a sense, also serves as its own backup. It is interesting to note here that the ratio between the thinnest and thickest elements is approximately 27 to 1. On the other hand, weld No. 2 might be considered a blind weld in that access to only one side is provided. This combination is 0.025 to 0.016 in. Finally, weld No. 3 joining the two trailing edges of the skins together is a joint between 0.025 and 0.025 in. against a copper backup, which serves also as a part of the positioning fixture.

Figure 11 shows two cross sections of the dorsal fin. In view A, the dorsal fin is shown to consist of four parts—a tube at the bottom with a 0.090-in. wall, a skin made of 0.042-in. thick material, an 0.042-in. thick internal stiffening channel which is the inverted "U," and a 0.025-in. thick leading or trailing channel which is the upright "U." View B shows a cross section through a rib, or leading or trailing tip forging. In both views, A and B, the thickness ratio is relatively large and a big heat sink is involved. In the case of the structure in view A, heat buildup during welding must be controlled so that the channels will not walk away internally from the skin. Similarly with the structure in view B, sufficient heat must be introduced into the forging while at the same time excessive heating of the thin skin section must be avoided. The control fin is fabricated of 17–7 PH stainless steel, whereas the dorsal fin is made from 1020 carbon steel.

The tape programmed welder shown in Fig. 12 is a basic machine concept which can be varied simply to meet many needs. The "X" and "Y" cross slides position the torches over the fixtured work, while the work platen or "Z" axis tilts so that the work surface directly beneath the torches is always perpendicular to the torch electrodes during welding. The heavy solid lines in Fig. 12 represent separation points in the basic machine assembly. Thus, each basic machine component can be removed for substitution of another component of different size and shape. This in turn adds to the versatility of the machine and makes it particularly adaptable for the fabrica-

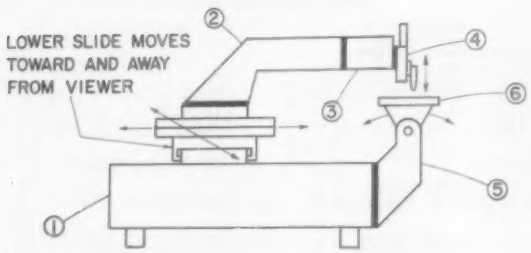


Fig. 12—Basic machine assembly for tape-control programmed tungsten-arc spot welding

Table 1—Typical Average Shear Values

Part	Top and bottom thickness, in.	Shear strength, lb
17–7 pH stainless steel control fin	0.025-0.016-spar	2100
	0.025-0.016	750
	0.025-0.025	1150
1020 mild steel control fin	0.042-0.042	1200
	0.042-0.025	550
	0.042-0.090	1300
	0.042-heavy variable forging	1400

tion of aircraft and missile components wherein literally thousands of spot welds may have to be located accurately with a fairly high degree of time efficiency.

The average shear values shown in Table 1 typify results obtained with the tape-control programmed tungsten-arc welding machine. Shear strength values as shown have, in most cases, comfortably exceeded original design requirements. As a result, in a number of cases, the actual number of spot welds finally used in both the control fin and the dorsal fin were appreciably reduced. In other words, experience has shown that fairly high shear values can be obtained with a dependable degree of consistency.

Design Considerations

When considering the possible application of tungsten-arc spot-welding, the designer is faced with a number of considerations. First, what is the range of material thickness which can be handled with the process and how many sheets can be spot welded together? Furthermore, what is the relationship in thickness between the two or more sheets which are to be joined? A second consideration is the permissible center-to-center spacing of spot welds and also permissible spacing from the edge of the sheet.

When considering joint thickness limitations as applied to stainless and carbon steels, the thickness of the top sheet of any joint should not exceed approximately 0.090 in. An exception arises in plug welding applications where the top sheet may be as much as 0.125 in. thick. Limitations on top sheet thicknesses now appear to be more an equipment rather than a process limitation. Some of the experimental equipment designs now being tested show excellent capabilities for joining materials as thick as 0.125 in. However, it is questionable whether commercially available equipment will produce the quality required for aircraft and missile applications on materials over 0.090 in. thick.

Referring to views A and B in Fig. 13, two possible combinations are shown joining two sheets together. In view A, the top sheet is considerably thinner than the bottom sheet, while view B shows a reverse combination. As a general rule when the thin sheet is to be welded to the thicker sheet, the only practical limitation is the maximum thickness of the top sheet—which as previously indicated is about 0.090 in. with existing equipment. When joining a thick sheet to a thinner sheet, the same limitation for the top sheet holds although the maximum thickness ratio between top and bottom is 3 to 1.

When considering multiple pile-ups as shown in views C and D, a pile-up consisting of more than three members has not proven practical. View C is a typical missile-fin joint described earlier where the top sheet was 0.025-in. thick, the center was 0.016-in. thick sheet, and the bottom was a very thick spar section. View D illustrates another triple pile-up where the thinnest section lies to the bottom of the pile-up. In this case, the thickness of the far side member should be equal or greater than 75% of the intermediate member thickness, except when cold wire addition is utilized whereupon this can be safely reduced to 60%.

When considering center-to-center distances of spot welds, one must consider the effect of the heat-affected zone surrounding each spot weld. In other words, as the center-to-center distance is reduced, a point will be reached where the effective strength of two spot welds transversely loaded will not be particularly in excess of a single spot weld, view A in Fig. 14. This is due to the fact that the heat-affected zones have now overlapped by a sufficiently large degree so that the strength of the joint is based solely on the annealed strength of the material. Therefore, as a general statement, the center-to-center spacing should be as large as design considerations permit.

The same consideration applies when determining the minimum edge margin along the edge of a sheet. A further consideration here, however, is the size of gas nozzle required for a given application. For example, a $^{6}/_{16}$-in. ID nozzle may be required for a given application. Assuming that the nozzle has a $^{1}/_{8}$-in. thick wall, the center of the spot weld would have to be located at least $^{1}/_{4}$ in. from the edge of the

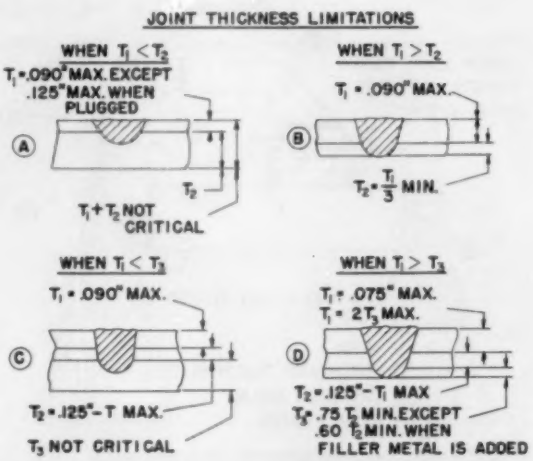


Fig. 13—Recommended thickness ratios

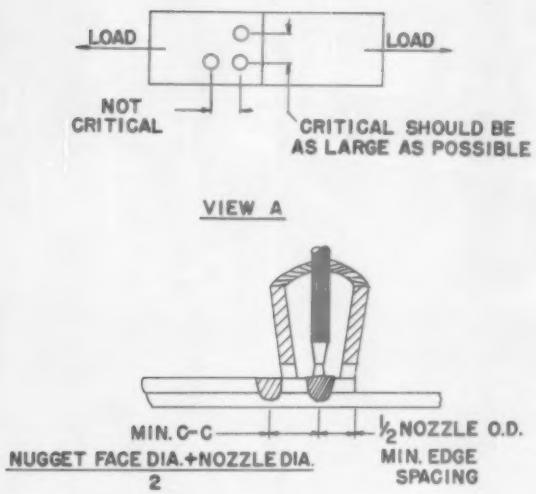


Fig. 14—Recommended center-to-center and center-to-edge spacings

sheet in order to permit the rim of the cup to rest squarely on the sheet at all points. As shown in view B of Fig. 14, the nozzle also establishes a minimum center-to-center spacing from a mechanical standpoint. The spacing must be great enough so that the nozzle does not rest on an adjacent weld nugget face.

Conclusion

Tungsten-arc spot welding is a valuable production tool for aircraft and missile manufacturers in both primary and secondary applications. The process has three features which make it ideal for the purpose:

1. Simplicity of application. All welds are made from one side of the joint only, with the result that joint accessibility is not a problem.
2. Flexibility. Depending on the requirements of a specific application, the torch may either be moved to the work or the work may be positioned under the torch.
3. Reliability. Shear strength variations no greater than 10 to 20% are easily achieved, and variations as low as 5% are entirely practical.

Mechanization of the tungsten-arc process is particularly advantageous with respect to spot-weld location accuracy, torch loading pressure and the speed of welding.

Acknowledgment

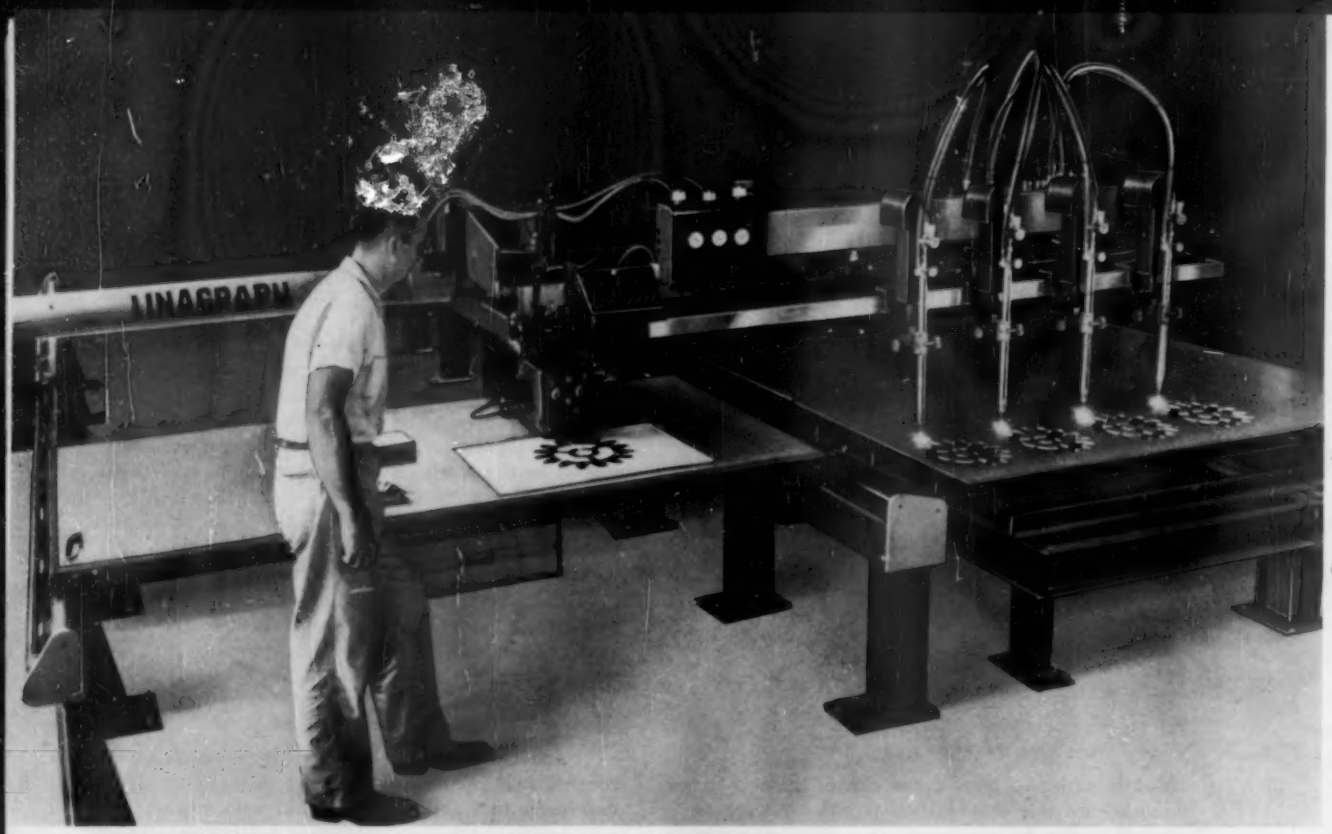
The author wishes to express appreciation to the several organizations whose cooperation in supplying test data and other background information was very helpful in the preparation of this paper. These include: Aerojet General Corp., Azusa, Calif.; Boeing Airplane Co., Seattle, Wash.; Convair/Pomona Convair Division of General Dynamics Corp., Pomona, Calif.; Grumman Aircraft Co., Bethpage, L. I.

An Important Reminder

AUTHORS...

January 15, 1961, is the deadline when application forms and abstracts must be postmarked in order to receive consideration for presentation at the 1961 AWS National Fall Meeting to be held in Dallas, Tex., Sept. 25-28, 1961.

The application form was included as a detachable insert in the October issue of the WELDING JOURNAL. Additional copies of the application, as well as "Instructions and Suggestions for Authors," may be obtained by writing to AWS headquarters, 33 W. 39th St., New York 18, N. Y.



Modern shape-cutting machine with an edge-following electronic tracer

Machine shape cutting with edge and line tracers involves the construction and use of templates as described in this discussion of the

Principles of **Template Preparation** for the Oxygen Cutting Process

BY L. M. LAYDEN

SYNOPSIS. Electronic tracing devices have come into widespread use for control of flame-cutting machines. Two general types of tracers are available, differentiated by the type of template required. Edge tracers require a template forming the outline of the part by a silhouette of black upon white or vice versa, whereas line tracers are capable of following an ordinary pencil or ink line.

Scanning principles of two types of tracers are discussed in this paper, and operating principles are related to the techniques of template preparation for each system. Techniques are discussed for compensating for cornering errors produced by the tracers and systems for compensating for the width of kerf are discussed. Selection of template material and methods of preparing the template outline are considered. Various other factors influencing the final accuracy of the cut part are discussed, and the paper concludes with a discussion of the relative advantages of line and edge tracers.

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Paper presented at the AWS National Fall Meeting held in Pittsburgh, Pa., Sept. 26–29, 1960.

History

Before the advent of electronic tracing devices, various different tracing systems were employed on shape-cutting machines. All made use of some kind of template, which acted as a guide for the tracing unit.

Magnetic tracers used a magnetized drive roller in contact with a steel or iron template. The tractive effort necessary to drive the machine was developed by the magnetic attraction between the drive

roller and the template. The spindle tracer was a simpler device, and the necessary force to provide traction was provided by the operator who had to maintain contact between the vertical drive roller and the edge of a cut-out template made from plywood or pressed wood. Another widely used tracing system used a formed metal strip as the template. The edge of this strip protruded up from the surface of the template and was gripped by a pair of knurled drive wheels which drove the cutting machine. The three systems described here all required elaborate templates which had to be prepared in the shop by a mechanic. Once the template was made, a large number of identical parts could be cut before the template was discarded or worn out.

Another simple system used a manual tracer, which was guided or steered around a drawing by the operator. This tracer consisted simply of a motorized drive wheel in contact with a tracing table and could be steered by means of a handwheel or knurled grip by the cutting operator. The template for guiding this device could be almost any kind of drawing. An ordinary shop blueprint complete with dimension lines and extraneous information could be used since an operator could distinguish between outline work and incidental line work such as centerlines and dimension lines.

A number of different automatic tracing devices are now available. They follow a prepared template optically by means of electronic servomechanisms. These devices also use some form of drawing as a template. However, since the servomechanism systems used are considerably simpler than those found in the average human operator, the preparation of the template must be tailored to the requirements of the particular tracing device. This paper will consider only templates for electronic tracers.

Scanning Principles

Two scanning principles are commonly used for electronic tracing devices intended to control general purpose shape-cutting machines. These tracing devices contain a drive wheel assembly which provides the tractive effort necessary to propel the cutting machine and a servomechanism which steers the drive wheel. In order to best understand some of the techniques of template preparation, it is helpful to understand the nature of the scanning systems. It is not the intention of this explanation to discuss the electrical design of the servomechanisms involved but rather to provide an understanding of the scanning principles.

The first optical tracing system used for the control of shape-cutting machines was an edge-following system—that is, the device centered itself over and followed the interface or edge between a dark and light area. This is accomplished by projecting a small, circular spot of light onto the template. The light reflected back from the template is picked up by a photocell system and compared electronically against a reference. If the amount of light reflected back is greater than the internal system reference, the unit will steer toward the dark area of the template. Conversely, if the amount of light reflected back to the photocells is less than the reference, the unit will steer toward the light area.

The other system used for electronic tracing devices is a line-following system. Here, a small photocell is vibrated by means of an electromagnet back and forth across a projected image of the line forming the template outline. The photocell, in its excursion back and forth across the line, passes from a light area (the background paper) through a dark area (the line) and then into a light area (the paper again). As long as the photocell "sees" light on one side of the line for the same length of time that it "sees" light on the other, no steering signal is produced. Thus the unit will continue to run in the original direction it is headed. If, however, the length of time that the cell "sees" light differs from one side of the line to the other, a steering signal causes the scanning system to rotate in a direction which will correct the error.

In both systems, the scanning device is contained in a rotating tube geared to the drive spindle of the tracing unit, such that the scanning system is always angularly matched to the position of the drive spindle. In each system, the scanning point is not exactly on the optical axis of the scanning system; rather, it precedes the optical axis in the direction of motion by a small amount. This slight displacement of the scanning point ahead of the axis of scanning spindle is called "lead." It has a pronounced affect upon the performance of the servomechanism device and upon the requirements of the template.

In order to explain the need for this lead, one might draw an analogy to driving an automobile. The driver of an automobile normally looks far ahead of his actual position in order that he may anticipate changes in direction in the road. This is basically the same reason why a tracing system requires lead. Another way to consider the problem would be to think of the tracing device as a self-contained entity not connected to a tracing machine. Under these conditions, think of the system as being balanced—the scanning unit is perfectly centered over the line or edge and no steering signal is produced. If the line were displaced slightly from this position, a steering signal would be produced which would require the steering spindle and the optical spindle to turn in a direction to correct this error. Since the scanning area is in front of the optical axis of the scanning barrel, this slight rotation will permit the unit to regain equilibrium even though it is standing still and not proceeding along the line. In this simple case, the dynamic performance of the servomechanism is entirely controlled within the scanning head system itself.

If the tracing device is mounted on a cutting machine and is moving along the line, it can be seen that lead is not an essential requirement of the system in order to permit it to seek equilibrium

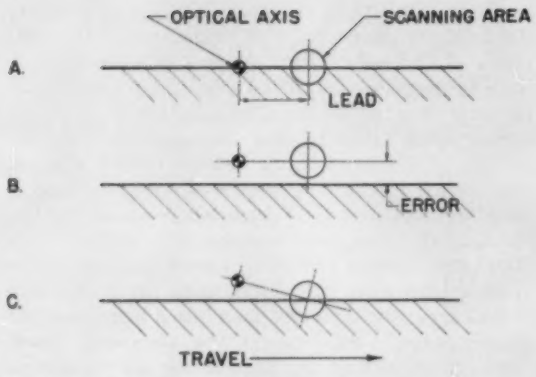


Fig. 1—Scanning spot lead in tracing devices

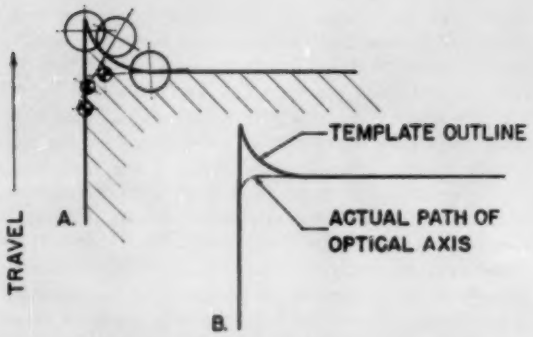


Fig. 3—Corner correction techniques for edge follower templates

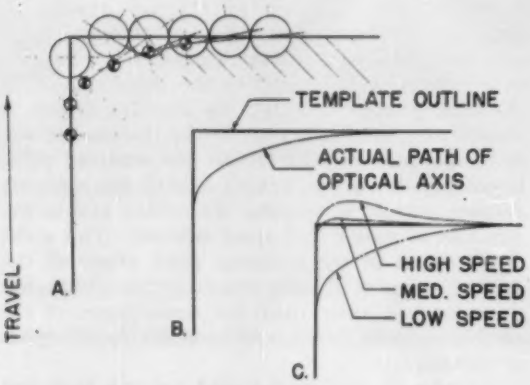


Fig. 2—The effect of lead on following a square corner

conditions. Even if the scanning spot were directly on the axis, a slight displacement would still create a steering signal which would tend to correct the error. A problem would occur in this case, however, since without lead the system would very likely become unstable in that a very slight displacement would call for a violent steering maneuver which could easily send the system into oscillation. The mass of the cutting machine is now included within the servo loop, and problems of stability become much more severe. By introducing lead into the system, the error is corrected immediately the steering action takes place and no violent oversteer is produced.

A reference to view A in Fig. 1 may make this explanation clear. Here the unit is perfectly centered on a straight line and is proceeding in a direction indicated by the arrow. In view B, consider that an error has been created such that the scanning system is displaced slightly to one side of the line. A steering signal will be generated, and the unit will turn in the direction necessary to correct the error. In view C, the system is back in balance in that no error signal is produced. However, the optical axis of the system is still displaced from the line. This produces a slight angularity between the direction of motion of the tracer and the line. The unit following along this angular direction of motion will move toward the line and the error will be corrected. An edge follower system is used in this example, but the same principle applies to line followers.

While it can be seen that lead is necessary to provide a stable system, it does create problems when sharp changes in direction are encountered. View A in Fig. 2 shows what happens when a tracing system containing lead tries to go around a square corner. It can be seen that, although the system is maintained in balance, the optical axis of the system will inscribe the square corner. In actual practice, this is the type of corner error that is produced by either system when operated at a very slow cutting speed. As cutting speed increases, this error will be minimized because of overshoot in the servo system. At some speed, an optimum cornering effect will be produced where the sharpest corner is produced. If the speed exceeds this optimum, there will be an actual overshoot of the optical axis of the system as shown in view C of Fig. 2. (Cornering error is discussed in a separate section of this paper.)

When discussing the two scanning systems, one further difference should be pointed out. If an edge-following tracer is placed entirely in a black area, it will circle in the direction required for it to find a light area. If it is entirely in a light area, it will circle in the opposite direction looking for an edge where the system will be in balance. This means that, if at high speeds the overshoot is so great that the scanning spot moves entirely off the interface between dark and light, the unit will still steer in the proper direction to correct the error. The lead will allow this spot to sweep entirely off the edge, swing around, and find the edge again. With a line-following system using the vibrating scan, if the scanning area moves entirely off the line, no steering signal is produced and the unit will

continue to move in the original direction it was headed. Systems of this type are usually provided with an auxiliary circuit, which will stop the cutting travel if the steering signal is lost. The fact that edge followers can produce a steering signal when completely off the template is significant in correcting cornering errors.

Tracer Errors and Template Compensation for Tracer Errors

The type of error normally produced when turning a sharp corner has been discussed above. In actual practice, this is the only significant error produced by the electronic tracing devices. There is an error possible due to dead-band in the servo system used. This error would appear on straight lines and would be very slight—normally not exceeding three to five thousandths. This is well within the accuracy expected from the cutting process.

When edge following tracers are used, it is possible to compensate almost entirely for the cornering errors introduced by the lead in the system. This is done by altering the contour of the template in the corner in such a way that the scanning spot is carried beyond the normal outline of the part. This produces a rapid steering toward the line, and the net effect is that the radius in the corner is greatly reduced.

The corner correction is shown in Fig. 3. In actual practice, such correction is necessary only when high-accuracy mechanical parts are being cut. An example of this is illustrated in Figs. 4 and 5 where Fig. 4 shows the template for a portion of a gear rack and Fig. 5 shows the actual part cut from this template. Two teeth of this rack have

Fig. 4—Rack template—two teeth have corner corrections

Fig. 5—Rack cut from template in Fig. 4

no correction, and considerable rounding of the corners can be seen. The cornering error is completely eliminated on the outside corners of the other two teeth.

Looking back at view C in Fig. 2 and view B in Fig. 3, it can be seen that the need for corner compensation varies with cutting speed. There is also a considerable variation between machines made by different manufacturers. For this reason, it is desirable to check the cornering performance of the particular unit involved at various speeds and to prepare a chart showing the dimensions of the corner modification required at various cutting speeds. Where work of the highest precision is desired, the particular tracing unit should be tested on the cutting machine with which it is to be used. Since the inertia effects of the cutting machine may vary depending upon direction of travel, compensation may vary depending upon direction.

It is not possible to provide this type of corner compensation on line followers. In fact, many line followers require that a radius be drawn into sharp corners which further increases corner error.

Kerf Compensation

Discussion thus far assumes that the cut part is the same as the outline produced by the tracing device. In actual practice, of course, this is not the case because the kerf produced by the cutting torch has a finite width. Furthermore, the part cut will be smaller than the traced outline because of this kerf width. In addition to affecting the size of the part cut, the width of the kerf also has a pronounced effect upon the shape of the corner produced.

There are two ways by which compensation for the width of kerf can be made. The most obvious way is, of course, to alter the size of the template such that the final part will be to the desired dimensions. The simplest way to alter the size of the template for kerf compensation is to first draw the outline of the part full size. On a complicated part, it is much easier to determine which side of the line requires alteration to provide kerf compensation by looking at the completed outline. This is preferable to attempting to calculate new dimensions beforehand. The photocells used in most line followers are highly sensitive to red light; red appears to the photocell the same as white. Thus, it is possible to draw the full size outline in red and make the kerf compensated outline in black, thereby eliminating need to erase the original outline. The tracer will then ignore the red lines and follow the black.

Some tracing devices provide an adjustable compensation for kerf width which can be used provided that no sharp changes in direction are required. This can be explained by looking at Fig. 6. Compensation for kerf width is produced by displacing the scanning spot to one side of the optical axis. Thus, in addition to the displacement in the direction of travel—here called "lead"—there is a displacement to one side for kerf compensation. The

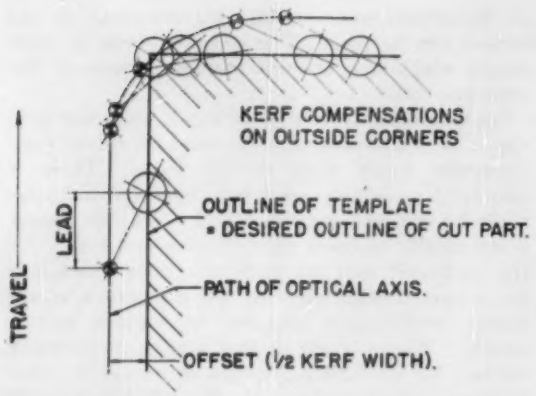


Fig. 6—Scanning spot offset for kerf compensation

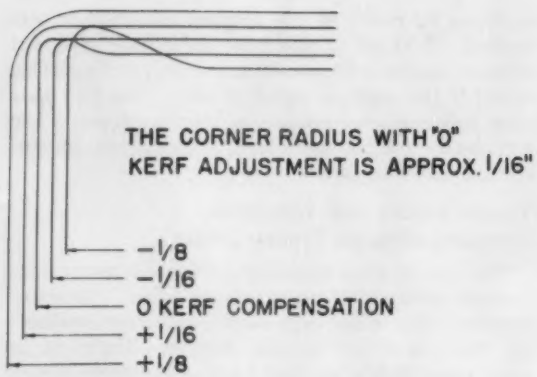


Fig. 7—Cornering errors produced by kerf width adjustment

net effect is the same as if the lead were inclined to the direction of travel. This distortion of lead is of little consequence along a straight line or gradual curve; it becomes more significant on sharp curves or square corners. From a practical viewpoint, kerf compensation by means of scanning spot offset cannot be used on templates having sharp changes in direction. There is considerable possibility that the servo system would lose control under sharp correction changes or that excessive error would be produced in the accuracy of the trace. The cornering error produced by kerf compensation by scanning spot offset is shown in Fig. 7.

Scanning spot offset can be produced to a limited degree in edge followers by altering the setting of the balance control. This control is normally set to center the spot of light over the outline of the template. However, it is possible to displace this spot up to approximately half its diameter by altering the setting of the balance control. The same drawbacks apply as mentioned above.

Kerf width produces another factor in template preparation; i.e., corner conditions are affected by the width of the kerf. If the tracing device rounds off a square corner by a radius equal to the kerf radius, the effect upon an outside corner will be to produce a sharp corner. The effect upon an inside corner will be, of couse, to increase the radius of the corner by an amount equal to the kerf radius. This is shown in Fig. 8.

A sprocket cut by a line follower is shown in Fig. 9, and the template for this part appears in Fig. 10. Note that, although a radius is drawn at the point of each tooth, the cut part has sharp teeth.

Template Materials

Various materials are available for use in the preparation of tracer templates. The choice of material depends upon a number of factors, including: size of template, accuracy required and whether the template is for a line or edge follower. Materials may be classed as being either flexible or inflexible. Commonly used flexible materials

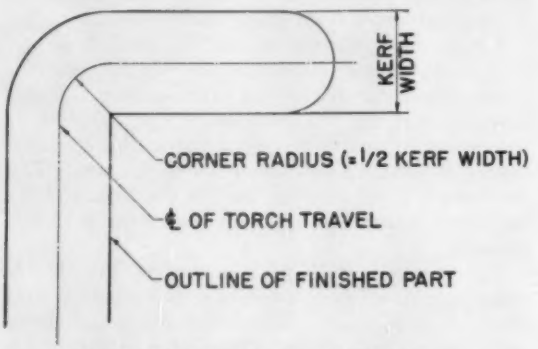


Fig. 8—The effect of kerf width on corner shape

are paper, bristol board, glass cloth and plastic film. Commonly used inflexible materials are metal sheets and tempered hard board or similar products. Flexible materials are normally used for smaller parts. Inflexible materials are used where very large templates are to be handled and might easily be torn; they are also used where certain special techniques are used which will be discussed later.

If the template is to be used immediately after preparation where only a few parts are required, ordinary white drafting paper may be used. If better durability is required, bristol board may be used. The preferred type of bristol board is usually known as "patent office" type and has a higher dimensional stability. The principal drawback to both paper and bristol board is that they are quite sensitive to changes in humidity. Both bristol board and paper have a humidity coefficient of expansion of about 125×10^{-6} in./in./% RH. Thus, if a template 50 in. long is prepared at 40% relative humidity and used in the shop at 80% relative humidity, an error of 0.250 in. will be produced. Where greater accuracies are required and where high changes in humidity are expected, materials with higher dimensional stability can be used. Glass cloth-based drafting material has a much lower humidity coefficient of expansion of approximately 6×10^{-6}. However, this material must be coated

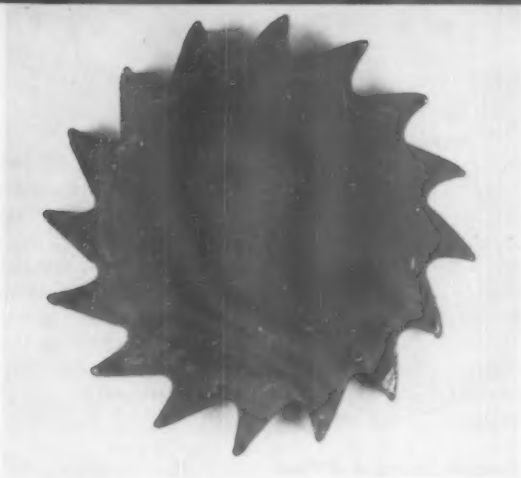


Fig. 9—Sprocket cut by line follower

Fig. 10—Template used in cutting part shown in Fig. 9

with a white coloring to produce a high enough contrast to actuate the tracing system. Another high-stability material has a plastic film base and is provided with a white surface which will take pencil or ink lines. Material from some vendors has a humidity coefficient as low as 6×10^{-6}. In the example above, the error produced by one of these materials would be only 0.012 in.

Where large areas are to be cut or where the template is subject to a great deal of handling, it is often desirable to use an inflexible material such as metal or tempered hard board. Tempered hard board is available with a flat black surface which provides sufficient contrast when used with white tape or paint outlines for edge followers. This material has a humidity coefficient of expansion of approximately 70×10^{-6}. Therefore, it is not as dimensionally stable as the glass cloth or plastic film materials described above. However, because of its much greater bulk compared to these thin film materials, dimensional changes due to humidity will not occur as rapidly. Thus if templates are stored in an area where humidity is held relatively constant, no great dimensional changes will take place for some time after the template is put into the shop. Where the ultimate in dimensional stability is required, thin steel sheets may be used as the template material.

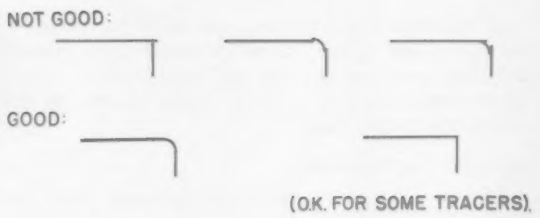


Fig. 11—Corner techniques for line followers

Methods of Making the Outline

Line followers find their greatest application in relatively short-run low production operations. Here the most common method of forming the template outline is to use a soft pencil on paper or bristol board. The draftsman need only make a line of good density with reasonable line width. Most line followers require a 0.020 to 0.040-in. wide line. Many require that a radius be drawn into a corner, while some will follow a square corner without any radius. It is important, on sharp changes in direction, that the line be crisp and dark and that there be no overlaps or tag ends protruding from the line to cause spurious steering signals. See Fig. 11 for examples of proper technique in constructing corner intersections. In most cases where the corner shape of the finished part is not critical, it is possible to draw the corner radii freehand which greatly speeds template preparation. Where a more finished job is required, a draftsman's circle template may be used to draw the corner radii. Where line templates are used in repetitive production, better durability will be attained if the template outline is formed with India ink rather than pencil.

Various techniques are available to form templates for edge followers. Each method has certain advantages, and the method selected will depend upon the requirements of the template. For utmost accuracy and for parts where corner corrections are required, the best technique is to use India ink as the template medium. The outline may be drawn with conventional drafting equipment, and the required line width may be produced by filling in behind the outline with a brush. Present tracers operating on full-size templates require that the black area be at least $^1/_8$ in. wide. However, the contour of the back side of the line is not critical so that the draftsman may leave this surface irregular when filling in by brush.

A convenient technique, especially for short-run work, is to make the outline of the part by a paper cutout. If white paper is used and the template table is painted flat black, the template may be positioned on the template table as desired; contrast will be provided between the black background of the template table and the white surface of the cutout. With this technique, it is necessary that a clear plastic cover be used to hold down the template and to prevent the tracer wheel from disturbing the position of the template on the table.

A technique widely used on large templates is to use $^1/_8$- or $^1/_4$-in. wide white plastic tape against a black tempered hard-board background. Templates made in this way are easily altered in the event of a design change.

Special Techniques

Where numerous parts are to be made from the same thickness of material, it is often convenient to group these pieces onto a single large template. This permits most efficient use of plate since parts may be "nested" to minimize scrap. When this is done, it is also possible to connect the pieces by means of additional template lines or areas so that all parts are made in one continuous cut. In this case, pieces may be severed from the scrap as the cut progresses by use of a hand-cutting torch or the entire interconnected plate may be removed from the cutting area and the scrap cut away in a separate area, thus freeing the cutting machine for immediate use.

Another useful technique often employed in ship building operations is to use a single template for a series of parts where only a slight change in outline is made between the various cuts. Thus, for example, a series of ship floor plates differing only in the contour of the curved portion of the plate may be laid out on one template with the series of curves laid down with plastic tape. A gap is left at each end of the variable portions of the template. This gap is filled prior to making a cut with a section of tape, thus selecting the desired outline.

Other Factors Affecting the Accuracy of a Finished Part

Throughout this paper several references have been made to accuracy in template preparation and in the tracing device itself. There are, of course, other factors which influence the over-all accuracy of the finished part. These are discussed briefly below.

Cutting Process

The cutting process, itself, can produce considerable error in the finished piece. For the most accurate work, it is necessary that the cutting tip be accurately aligned perpendicular to the surface of the plate. This should be done by plumbing to the cutting oxygen stream as observed with preheat flames burning and cutting oxygen on. This will eliminate any inaccuracies in the torch or tip. Often an old cutting tip which has been frequently cleaned may exhibit a cutting oxygen stream which is nonsymmetrical. For the highest grade work, a test cut should be made around a square outline and the various sides of the square measured for perpendicularity of the cut with the surface of the plate.

Cutting Machine Errors

All present cutting machines are capable of reproducing the outline of the template to close tolerances within their entire area. In most cases, the manufacturer will guarantee a new machine to within $^1/_{64}$ in. over the entire cutting area. However, wear or damage to the machine may increase this error and for high-quality cutting the machine should be periodically checked. This is most conveniently done by using a radius rod with a manual tracing device at the tracing end of the machine to form a perfect circle and measuring the various diameters of a circle traced by the machine in the cutting area. A ballpoint pen attachment may be used in place of the cutting tip to trace the circular outline.

Thermal Expansion of Plate

A considerable source of error is the thermal expansion of the plate as the cut progresses. This is particularly troublesome with long, narrow parts where considerable warpage may take place as the cut proceeds in the long direction. As a general rule, thermal distortion can be held to a minimum by starting the cut by piercing within the area of the plate rather than starting on the edge of a plate. This restrains the scrap from warping, which can cause the plate to move on the cutting table. For high-accuracy mechanical parts, the plate should be supported within the outline of the finished piece with no restraint or support under the scrap.

Template Error

With ordinary care, template accuracy can be held to $\pm^1/_{64}$ in. With special equipment it is possible to cut this error to ± 0.005 in. This accuracy, of course, demands that dimensionally stable template material be used.

Tracing Device

Tracing errors were discussed above and ordinarily can be considered to be within the range of 0.003 to 0.005 in.

Relative Advantages

There are certain areas where each type of tracer will give advantages. In most cases where relatively small templates are used, template cost is lower for line tracers. Where very large templates are made by the tape method, it is probable that template cost is lower for the edge tracer. Where accurate mechanical parts must be made requiring sharp corners, it is necessary to use an edge-type tracer.

Edge tracers are less sensitive to dirt or smudges on the template than line tracers. However, they are somewhat more sensitive to changes in ambient light. Line tracers have no "direction sense," that is to say, if disturbed by mechanical jar or by a speck of dirt on the template, they can turn around on the line and trace back the opposite direction. This is not possible with an edge tracer. When considering the relative merits of one type tracer over another, the user should carefully analyze his own area of operation and choose the tracer which will produce the best results for him.

Practical Welder and Designer

Bonuses from Welding with CO_2 and Flux-Cored Wire . . .

Avery and Saul—welding fabricators in Cambridge, Mass.—recently developed several "bonuses" when using the Arcosarc process on machine bases—Fig. 1. For example, no beveling was required for butt and fillet welds in lighter sections. Furthermore, for heavier section butt welding it was found that the included angle could be reduced from 90 to 60 deg. Finally, where edge preparation was irregular, the visible and deep penetrating arc made it easy for welding operators to compensate for poor fit-up.

The bases were made from low- and medium-carbon steel ranging in thickness from $^1/_2$ to 6 in. Even though fabrication involved a variety of horizontal butt, fillet and corner welds, the results of tensile and bend tests on welds made by skilled operators disclosed excellent physical properties. The actual welding was carried out with a combination of wire drive unit, air-cooled gun, CO_2 shielding gas and flux-cored wire. This combination was used continuously, five to six days a week and 16 to 20 hr each day for welding bases similar to that in Fig. 2. Existing power sources—with a 600-amp capacity and drooping characteristics—were used.

The flux-cored wire as used for the machine bases has a $^1/_8$ in. diam and is made of a specially folded strip designed to hold and provide even distribution of the flux powder core. The powdered ingredients form a thin, compact, easily removed slag to shield the solidifying weld metal. During welding, the CO_2 gas shields the uncovered pool close to the arc. The finished beads are smooth and slightly convex.

Because of economies obtained in edge preparation and because of easy deposition of high quality weld metal in heavy sections, Avery and Saul have extended welding with CO_2 and flux-cored wire to pressure vessels and heavy bushings.

Based on story from Arcos Corp., Philadelphia, Pa.

Fig. 1—Welding of $^1/_2$- to 3-in. thick medium-carbon steel machine base with $^1/_8$-in. diam flux-cored wire, 50 cfh CO_2, 500 amp and 28 v

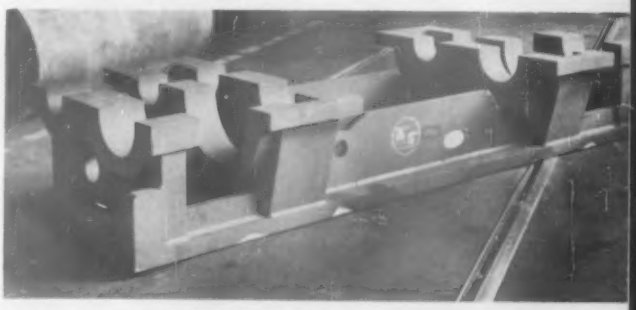


Fig. 2—Finished machine base with $^3/_4$-in. fillet weld made in two passes on positioned fillet using 500 amp, 28 v, 50 cfh CO_2, and $^1/_8$-in. diam flux-cored wire—3- to 6-in. thick medium-carbon steel base material—weldment stress relieved, cleaned, painted and inspected

Fig. 1—Delta-wing Hustler presents the shape of the future, as four-engine jet bomber carries disposable "pod" on simulated mission

Thin-Skinned Avengers

BY E. L. TRIMBLE

Stabbing like arrowheads into the sky, delta-wing B-58 Hustler bombers are now entering service with the U. S. Strategic Air Command (Fig. 1). Developed and built by Convair Division of General Dynamics Corp., Fort Worth, Tex., the 1300-mph B-58 is the newest member of SAC's deterrent arsenal.

Since Hustlers hurtle through the atmosphere at twice the speed of sound, air friction generates a great amount of heat which must be dissipated. The B-58's heat-resistant skin is fabricated of glass fiber, aluminum and stainless-steel honeycomb, sandwiched between two thin metal layers. This sandwich-panel construction insulates the understructure from aerodynamic heat, yet retains the required structural strength with minimum weight.

Intricate fabrication of the B-58 stresses speed and reliability. Because of the difficult problems encountered in fabricating the special materials used in the B-58, argon-shielded welding and cutting processes are used in many production phases.

Convair, for example, uses constricted tungsten-arc cutting primarily because of its *speed*. This process trims $^1/_2$-in. 7075SW aluminum alloy panel slugs to proper size, making straight-line cuts 440 amp, 60 v. The mechanized argon-shielded cuts are made at a speed of 85 ipm (Fig. 2).

Gas tungsten-arc welding is specified for fabricating B-58 elevon hinges, because of strict requirements for weld *strength* (Fig. 3). The hinges are fabricated from 0.2 $^1/_2$-in. high-strength steel by Amco-Weld, Inc., Abilene, Tex. Argon provides weld shielding and inert-gas backup.

A preheat temperature of 300–600° F is maintained throughout the 8-hr job. After welding, hinges are stress relieved at 1250° F and sand blasted. X-ray and fluorescent inspections are performed, followed by final machining. This modified tool steel is then heat treated in molten salt at 1850° F and air cooled, followed by triple tempering at 1025–1060° F. A stress level of 250,000 to 280,000 psi is produced at room temperature.

With the help of sound engineering and modern production methods, a major breakthrough in aviation technology was effected, and the B-58 Hustler was produced in record time. The thin-skinned avengers are now on guard for America, and freedom across the world.

E. L. TRIMBLE, Region Manager, Electric Welding Department, Linde Co., Kansas City, Mo.

Fig. 2—Tungsten-arc machine cutting at 85 ipm trims aluminum alloy wing-panel blank for Convair B-58 intercontinental bomber

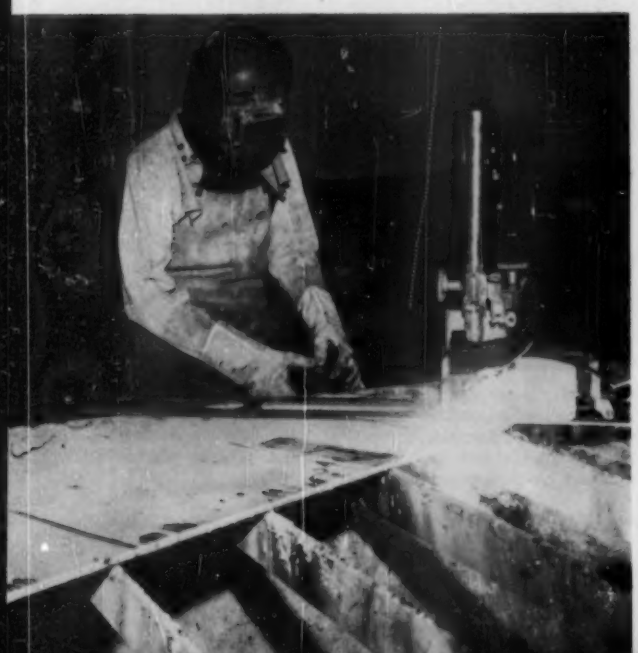
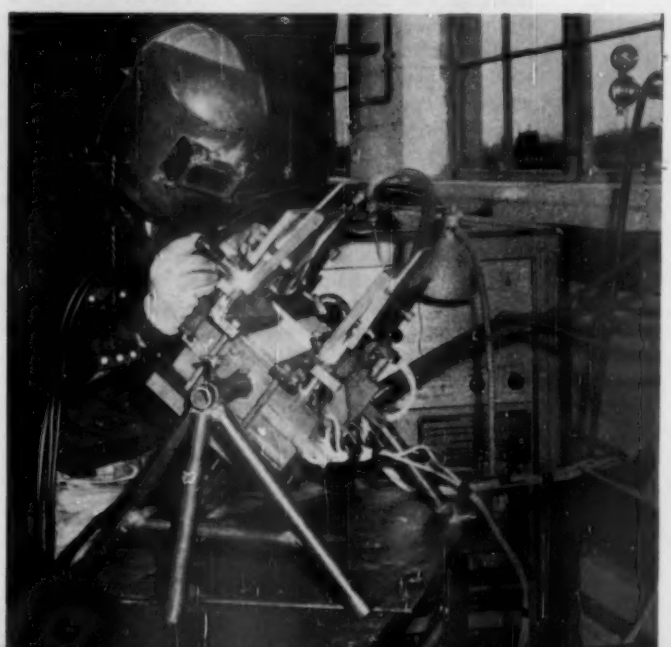


Fig. 3—Convair specifies high-strength tungsten-arc welding for B-58 elevon hinges, which are fabricated by Amco-Weld, Inc., Abilene, Tex.



Controls Wind Tunnel Air Flow at 2500° F

A butterfly valve disk, hard-faced along its circumference with a cobalt-chromium-tungsten alloy, plays a key role in controlling hot air flow between a pebble-bed heater and a wind tunnel at an aeronautical test center. The hard-faced disk, which makes metal-to-metal contact with the valve body, resists the erosive effects of a hot, abrasive air stream. At certain stages of the wind tunnel operation, the valve is closed against air at 2500° F and 275 psi for 1-min periods. At other times, air at 1450° F and 60 psi impinges against the valve for over a minute.

The 6-in. diam butterfly valve is manufactured by W. S. Rockwell Co., Fairfield, Conn. At the test site, a natural-gas burner brings the pebble-bed heater to the desired temperature. Air is then forced through the heater bed filled with alumina pebbles. The flow of the heated air into the wind tunnel is regulated by the butterfly valve.

Based on a story by Haynes Stellite Co. New York, N. Y.

The high-temperature problem inherent in this application is complicated by the abrasive nature of the air stream. This stream contains products of natural gas combustion, water vapor and some alumina fragments. A cobalt-base alloy designated Haynes Stellite Alloy No. 1 was specified for the job by the prime contractor because of its high hardness at elevated temperatures. High red hardness makes the alloy ideal for this application. Even after continued use, the valve disk is able to hold against air at 300 psi and 130° F with less than 10 cfm leakage.

The disk, made of ASTM-A27-55 cast steel, was preheated to the 1100–1200° F range before the $^{3}/_{16}$-in. diam bare cast rod was deposited by the manual oxyacetylene method. Six 12-in. lengths of rod were used to produce a $^{3}/_{32}$-in. deep layer of alloy on the circumference of the part. A rotating jig facilitated the operation, which took about 20 min. The deposit was ground to finished dimensions.

Fig. 1—Deposition of a $^{3}/_{16}$-in. wide band of Alloy No. 1 on the 6-in. diam disk takes 20 mins

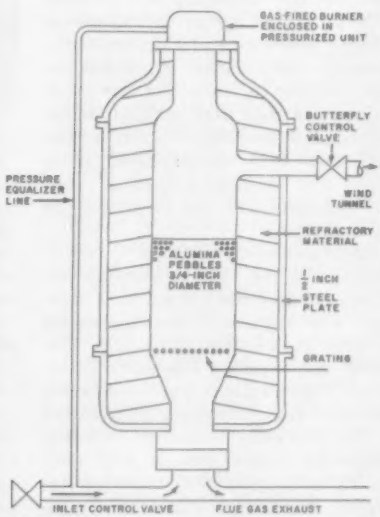


Fig. 2—Schematic diagram of the setup used to supply hot air to an experimental wind tunnel

Society News

International Institute of Welding to Hold First U. S. Assembly in New York City

Since 1948, the IIW has held 13 Annual Assemblies in various leading cities of Europe. Although 11 different countries have been visited in this way, the traveling distance for most of the delegates has not been very great. This year, however, the Assembly will be held in New York City at the Sheraton Atlantic Hotel on April 11th to 19th. Crossing the Atlantic is a considerable increase in travel for the great majority of members, so that, while the recent Assemblies have averaged well over 500 participants, it is hoped and estimated that at least 300 members will find their way to these shores.

Representation from North America in the IIW is through the American and the Canadian Councils. The American Council consists of the AMERICAN WELDING SOCIETY, the Welding Research Council of the Engineering Foundation and the Ship Structures Committee of the National Research Council. While all these groups will contribute in support of the coming Assembly, the major share will be assumed by AWS and by its local sections in the New York metropolitan area. Chairman of the American Council is National AWS Secretary F. L. Plummer; Rear Admiral E. H. Thiele of the Ships Structures Committee is vice chairman while AWS Technical Secretary E. A. Fenton is serving as secretary. Former IIW President Howard Biers is honorary chairman.

IIW TO Augment AWS Meeting

The occasion of the 1961 Assembly is a great honor to this country. In effect, however, it is more than this since members of the IIW will appear at the Annual Meeting and Exposition of AWS whose meeting dates of April 17–21, at the Commodore Hotel in New York, overlap those of the IIW. This unusual opportunity of having both the Meeting and the Exposition augmented by European experts will greatly increase the scope and the interest in the AWS activity. While the meetings of the IIW are necessarily restricted, it has been the custom to hold a public session during which original papers prepared for the occasion are discussed under the direction of a moderator. An interesting example of the way the IIW operates is given in this instance by the fact that the papers are not read at the session. Instead they are preprinted and distributed in advance to all who wish to attend, the result being that a maximum amount of time is available for valuable discussions. At present, it is not known whether this method will be followed completely next April. At least three lectures will definitely be presented as such by members of the IIW. They are the AWS Adams Lecture, the Educational Lectures and the annual IIW Houdremont Lecture.

Success of the IIW

During the past 12 years the IIW has developed to become a highly successful organization not only by reason of its success in the field of welding itself but also because of its efficient liaison with other groups and its effective methods of securing a truly international collaboration. Some of the details of the structure and the method of operation which make the IIW rather unique were published in earlier issues of the Journal.* Although the method of organization and the degree of international cooperation achieved have had much to do with its success, a dedicated leadership has nourished the IIW from its birth. The men whose wisdom created it and whose energies fostered its growth are still among its greatest assets.

Present Officers of the IIW

The names and a brief description of some of the officers who will lead the 1961 assembly are given herewith. Space does not permit more than a short summary of the background of the president and the two permanent secretaries.

President
W. Edstrom, Sweden

Vice Presidents
F. Frenay, Belgium
H. Kihara, Japan
F. L. Plummer, United States
G. Vedeler, Norway

Secretary-General
G. Parsloe
54 Princess Gate, Exhibition Rd
London, S.W. 7, England

Scientific and Technical Secretary
A. Leroy, France

Treasurer
H. E. Jaeger, Netherlands

*See WELDING JOURNAL for October, November December, 1960.

Presidents of 15 Commissions

I. C. G. Keel, Switzerland
II. H. E. Jaeger, Netherlands
III. H. G. Taylor, United Kingdom
IV. A. L. Blosset, France
V. G. A. Holmes, Belgium
VI. F. M. L. Van Horenbeeck, Belgium
VII. A. Leroy, France
VIII. L. André, Sweden
IX. K. D. Rühl, West Germany
X. R. Weck, United Kingdom
XI. J. Cattel, Netherlands
XII. M. Komers, West Germany
XIII. H. de Leiris, France
XIV. A. Naess, Norway
XV. U. Guerrera, Italy

●

W. Edstrom

One of the founders of the IIW, Walter Edstrom took part in the early provisional meetings and was elected the first treasurer in 1948. From 1951 to 1953 he was vice president. Becoming chairman of the Publications Committee in 1956, he continued in this post and that of treasurer until 1959 when he was elected president for the three year term from 1960 to 1962.

Mr. Edstrom matriculated at Malmö in 1909 and received his M.S. (Electrotechnics) from the Royal Institute of Technology in 1913. Starting as an engineer and later as a manager he was employed with ASEA in Sweden and Russia, with A/B Elektraverken in Stockholm and with Siemens Schuckertwerken in Germany and Spain. President of ESAB from 1931 to 1956, he has been chairman of the board since 1957.

Among many other activities he has been honorary consul to Mexico, consulting engineer and lieutenant colonel in the Swedish Army, member of Swedish Parliament. He holds or has held directorships and trusteeships with 15 commercial and professional societies. In addition he has received the silver and the gold medal from the Royal Swedish Academy of Engineering Sciences and has been decorated by Sweden, Finland and Germany.

A Rotarian, he is also a member of four sports clubs.

●

G. Parsloe

Guy Parsloe, M.A., came into welding in 1943, on appointment as secretary of the Institute of Welding. He has been secretary-general of the International Institute of Welding since its formation in 1948 and was one of the provisional committee which brought IIW into being. He was secretary of the OEEC Welding Mission which visited the United States for six weeks in 1953.

His hobby is historical research and he is the author of many books and articles on historical and bibliographical subjects. The first half of his working life was spent as an official of the University of London, secretary and librarian of the Institute of Historical Research. He is married and has a daughter and two sons.

●

It is not possible here to do justice to the career of Andre G. P. Leroy; so, with apologies, the highlights are set forth. His activities with IIW began with its inception when he was a member of the Governing Council and chairman of the Commission on Standardization. Since 1950 he has been scientific and technical secretary.

As head of the French Institute of Welding he runs a staff of 230 engaged in research, studies, tests, inspection, documentation, standardization and teaching at levels from operator to engineer.

A. Leroy

Along with his executive duties he has managed to continue his early chief interests in welding metallurgy research and teaching. His early training for these pursuits culminated with his graduation, with honors, as an engineer from the College of Industrial Physics and Chemistry at Paris, in 1930. Parallel careers with the Welding Institute and the School for Autogenous Welding saw him rise to director of both from 1942 to the present and to trustee for the latter since 1943. Since 1946 he has been secretary-general of the Society of Welding Engineers. From 1948 to now he has been a member of the Steering Committee and president of the Standards Commission of the IIW as well as secretary-general of the Permanent International Committee for Acetylene and Autogenous Welding. In 1951, Mr. Leroy headed the French Welding Mission to the U. S. He has several times been the president of the Full Committee ISO/TC 44 "Welding."

A Chevalier of the Legion of Honor, Mr. Leroy has been awarded gold and silver medals for work in his field. An honorary and regular member of 9 societies related to engineering, welding and metallurgy, he has written or collaborated in the writing of over 90 articles, chapters, monographs on all phases of welding, corrosion, metallurgy and inspection.

KEEPING YOU POSTED

by Fred L. Plummer

● Again I send you New Year Greetings and express the hope that this year may bring you much joy and many successes. Two outstanding events will highlight the year for AWS: being host for the 1961 IIW Assembly during April and the move to new UEC headquarters during late summer.

● During late October Vice-president A. F. Chouinard met with AWS Sections at Madison, Wis., and at Danville (Eastern Illinois) where he presented an Adams Memorial Membership Award to Prof. Walter H. Bruckner of the University of Illinois. Director L. L. Baugh assisted n the presentation of this award.

● Past-president C. I. MacGuffie was principal speaker at a meeting of the Lehigh Valley Section during October and on November 14th spoke at the opening-day dinner for those attending the five-day course devoted to inspection and testing, and organized by the AWS School of Welding Technology under the supervision of our EAC and Staff Member A. L. Phillips, Vice-president C. E. Jackson, EAC Vice-chairman E. E. Goehringer and Special Course Chairman Charles Witherelo also participated in this program.

● Vice-president J. H. Blankenbuehler met with the Nashville Section during October, giving a technical lecture and presenting a Neitzel Membership Award to the Section. Early in November he met with the Tulsa Section presenting the principal address and receiving a pledge to the UEC Building Fund covering the full quota for this Section.

● On October 27th President R. D. Thomas, Jr., and your Secretary joined with the Niagara Frontier Section of Buffalo in their National Officers' Night Dinner and Meeting. Following brief remarks by Director J. W. Kehoe, your Secretary outlined current SOCIETY projects and then President Thomas discussed "Some Dramatic Applications of Stainless and Low-alloy Steel Welding." Chairman W. L. Burch, assisted by Officers Bob Siemer, Sam Corica, Bob Saxton and others conducted the meeting which was well attended by enthusiastic and active members including Frank Neary, Fred Brown and Frank Iapalucchi, recent chairman of the Philadelphia Section.

● Assistant Secretary Frank Mooney started a well earned and long delayed vacation in Florida on October 31st. A card from the Everglades Hotel indicated that as of mid-November he was enjoying a daily swim and ideal weather. Before returning to New York for Thanksgiving, he conferred with a group of men interested in forming a new AWS Section in the Jacksonville area.

● Also on October 31st Education Secretary A. L. Phillips called to order the first of three special five-day courses now planned for the current fiscal year by the AWS School of Welding Technology. President Thomas presented an entertaining and quite fantastic series of analogies between his fall gardening of the previous weekend and welding metallurgy (the subject of the course) to give a perfect finish to the first day of serious discussions and the complimentary dinner attended by those participating in the course. Treasurer H. E. Rockefeller, Vice-president C. E. Jackson and your Secretary also spoke briefly in the dinner program chairmaned by Charles Witherelo.

● Chief Engineer Fred Emhart of Struthers-Wells Co. lunched with your Secretary on November 2nd and discussed activities of companies in and near Warren, Pa., where your Secretary served as Director of Engineering of a steel plate fabricating company for 17 years.

● The following day President Thomas and your Secretary flew to the Albany airport where they were met by C. H. Kreischer, driven first to a hotel in Schenectady and later to the dinner meeting of the Northern New York Section where they were greeted by many prominent AWS members including Director Jay Bland, Roger Clark and Walter Fleischmann. Chairman John Cuturilo, Secretary Leon Walker, Vice-chairman Kreischer and W. A. Owczarski were in charge of the social period, dinner and meeting during which President Thomas presented an Adams Memorial Membership Award to Prof. Robert A. Wyant now of Clarkson College of Technology and previously with Rennsselaer Polytechnic Institute. President Thomas also presented a technical talk and led active discussion on "Electroslag Welding" following brief remarks by your Secretary.

● Election Day found President Thomas and your Secretary, having exercised their voting privilege by absentee ballots, meeting in Birmingham for lunch with Section Officers, Past-director A. E. Pearson and leaders of the welding industry in that area. During the day President Thomas visited the plant of Chicago Bridge and Iron Co. and your Secretary that of Pittsburgh Des Moines Co. (formerly Hammond Iron Works) where he was guest of Executives Newell, Lisby and Pittman. Section Officers W. W. McCain, E. T. Estock and K. V. Nickell conducted the dinner meeting that evening at which President Thomas discussed stainless and low-alloy steel welding following remarks about AWS activities by your Secretary. Chairman McCain presented to President Thomas a check and pledge for the UEC Building Fund as Past-chairman R. A. Davis recalled that he had presented one of the earliest contributions to G. O. Hoglund who was then AWS President. The Birmingham Section has pledged full payment of its quota to this fund.

● Early the following morning President Thomas, Clay Birkhead and your Secretary were guests of W. W. McCain and his associates, enjoying a tour of the Groslin-Birmingham Mfg. Co. plant and inspection of the wide variety of large weldments being fabricated by various welding processes.

● Successive plane flights then carried President Thomas and the writer to Atlanta and on to Cleveland where we met that evening with the Cleveland Section at the Engineering and Scientific Center. Following a social period with old and new friends including Ed Scott, Ray Tarbell, Ross Yarrow, Frank Flocke, Bill Mayor, Tom Dempsey, Bruce MacPherson, Bob Kriz, Charlie Herbruck and many others, officers Bob Pagenkopf, Wasil Romance, Charles Berka and J. Darbyshire presided at the full meeting at which your Secretary discussed the new UEC head-

quarters for the AWS, President Thomas outlined some current AWS activities, R. Meyers of Harnischfeger and W. Gallo of Thew Shovel presented illustrated talks describing welding of heavy earth moving and hoisting crane equipment. H. Bolander served as technical chairman for the meeting.

● The next day with President Thomas continuing to Detroit for conferences with associates in that area, your Secretary was guest of managing Director Allan Ray Putnam of ASM at their new headquarters at Novelty, Ohio. At lunch and during the day your Secretary had an opportunity to confer with Department Heads DuMond, Thum, Gray, Ford, Brasunas, Lyman, Hilty and others as well as Director Putnam and Society for Nondestructive Testing Secretary P. D. Johnson who was also visiting ASM. The fine facilities and modern procedures of this outstanding group were carefully inspected. The generous hospitality of Director Putnam and his staff was thoroughly appreciated.

● Continuing to Detroit on November 11th your Secretary joined President Thomas for a dinner meeting of the Detroit Section which followed a ceremony at Greenfield Museum celebrating the 75th anniversary of the construction of the first electric welding machine by Elihu Thomson. A duplicate of the original machine, housed in the museum, was operated during the ceremony which was planned by Al Hackett and officers of the Detroit Section, and viewed by representatives of TV and the press.

● Following dinner at the Detroit Engineering Society Center, President Thomas gave a coffee talk in which he emphasized the importance of study and use of new welding processes and techniques so that our industry can maintain its strong position in world markets in competition with that of other countries where new developments are being adopted and utilized effectively to improve economy and increase production rates.

● President Thomas presented his talk "Some Dramatic Applications of Stainless and Low-alloy Steel Welding" after your Secretary discussed AWS projects and received a check from Chairman A. W. Brown bringing the total contributions of the Detroit Section for the UEC Building Fund to a figure in excess of their quota. Directors Ray Stitt and Ray Hoeffler, Past-director Keith Sheren, Past-chairman R. B. Wilcoxon and Section Officers Brown, A. E. Lindsay, R. P. Wolgast, J. C. Cox, H. V. Beronius, L. E. Wagner and many other directors, committee chairmen and members attended this successful meeting. Following the meeting members of the Section Executive Committee entertained President Thomas and your Secretary at a social and conference session which continued well past midnight. Uneventful plane flights carried President Thomas and your Secretary to Philadelphia and New York, respectively, the following Saturday morning.

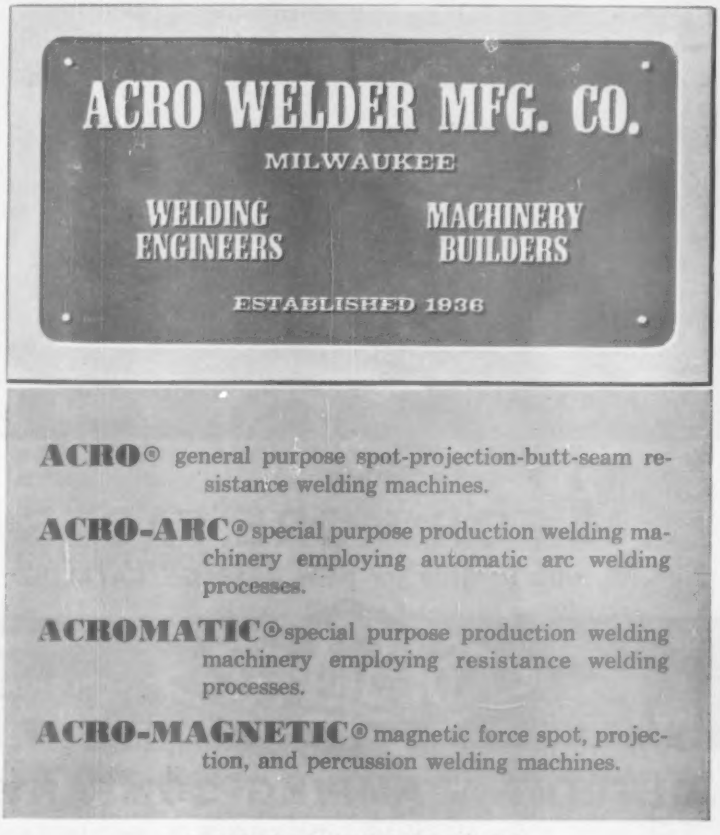
● On Monday, November 14th, with Past-president MacGuffie addressing the dinner meeting of the AWS School of Welding Technology special course attendees in New York, President Thomas spoke at a national meeting of the Steel Founders Society in Cleveland.

● The next day your Secretary lunched at the Union League Club in Philadelphia with President Thomas and NWSA Executive Secretary Bob Fernley. Further cooperation of these two friendly and closely related groups in connection with national meetings, educational and other projects was discussed.

● Following lunch an auto trip with President Thomas in the driver's seat brought us to a dinner meeting of the York-Central Pennsylvania Section at which Chairman J. L. Long, Past-chairman J. O. Cavanaugh and Officers S. Hughes, C. Allen and T. H. Boyer were in charge of the large group representing all important manufacturers and fabricators in this area. President Thomas and your Secretary repeated their discussions concerning stainless steel welding and AWS projects.

● On November 7th and again on November 17th your Secretary was pleased to welcome Y. Funo, President of Toyo Kanetsu Kogyo K. K., a metal fabricating firm of Tokyo. On the later date Mr. and Mrs. Funo visited with Mrs. Plummer and the writer in Stamford and sampled an early but typical American Thanksgiving dinner.

● The Engineers' Club in Baltimore was the location for the November 18th meeting of the Maryland Section at which past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chairmen were honored. Chairman Richard Metius introduced twenty or more individuals who had served as chairman of the Maryland, Philadelphia or Washington Sections. The writer can recall the following names of some of those included in this distinguished group: Basil, Christenson, Claussen, Clements, Earlbeck, Jones, Less, Linnert, Lutes, MacPherson, Matthews, Ronay, Sayre, Silby and Thomas. Your Secretary gave an "after dinner speech" and welcomed a promise that the Maryland Section would complete the payment of its full quota to the UEC Building Fund during the current fiscal year. President Thomas again presented his thought-provoking and informative discussion of stainless and low-alloy steel welding applications. Officers John Benson, Kermit Sanders and Frank Jones assisted Chairman Metius in conducting the meeting.

● Norman Farrell who attended this meeting as a member of the Section Executive Committee, joined your headquarters staff as Assistant to Technical Secretary Ed Fenton on November 28th.

● These notes are being written on an airplane late at night on November 18th. President Thomas and your Secretary will complete their visits with Sections for the current calendar year in Philadelphia and Cincinnati on November 21st and 22nd. During January 1961 President Thomas will meet with Sections in Minneapolis, Portland and Seattle on 9, 10, and 12. Your Secretary will speak in Montreal on the 13th at a symposium organized by the Canadian Welding Society. Vice-president C. E. Jackson and your Secretary meet with the Holston Valley Section on the 17th. President Thomas and your Secretary will join Sections at Toledo, South Bend and Chicago on the 18th, 19th and 20th.

● Former AWS Secretary J. G. Magrath is now associated with Eutectic Welding Alloys Corp.

Welcome

● Supporting Member

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EDUCATIONAL ACTIVITIES

AWS School of Welding Technology

The fourth course given by the AWS School of Welding Technology was held November 14th through 18th at the Sheraton-Atlantic Hotel in New York City. This hotel, incidentally, will be the headquarters hotel for the International Institute of Welding, which is holding its annual meeting in New York the week prior to our own Spring Meeting.

Testing and Inspection of Welds was the title of the course, and it drew students from all over the United States and Canada. Enrollments closed the week prior to the course and those who applied later were disappointed. We had applications for this course right up until the Tuesday evening after the course had started, which gives an idea of the popularity of the subject and the need for courses of this description.

On the Monday evening, the usual get-together dinner was held and practically all of the students attended. Charlie Witherell, chairman of the Course Committee, acted as chairman. He introduced the various instructors who came to the dinner in order to meet the students, and also introduced the officers of the SOCIETY.

Clarence Jackson, vice-president of the Society, performed some feats of magic which were greatly appreciated by the diners. Charlie MacGuffie, past president of the SOCIETY, gave a short address in which he stressed the value of education and the need for such programs as we were presenting during the week.

The first course we gave contained 50 students, and among these students there were 35 different classifications of engineers. This indicates how extremely difficult it is to present a course which will give each student exactly the information he requires. The course concluded in November had an equally diverse group. The classifications ranged from chemical engineers to metallurgical engineers, and from training instructors to representatives from the Marshall Space Flight Center. We had inspectors, materials testing engineers, repair superintendents, plant engineers; in fact we had a cross section of most categories of engineers.

These courses are serving the purpose for which they are designed. They present a crash program on a particular subject. They cram into four and a half days what would probably take six months to cover adequately. It is utterly impossible for any student to remember all that is given at such courses, but each student is provided with a notebook, a textbook and various outlines and similar material to which he can refer later on.

Spring Section

The next course to be held will be on Industrial Piping, and it will be given at the Sheraton-Atlantic Hotel, New York City, Feb. 13–17, 1961. The course is open for enrollments now and all prospective students should endeavor to make reservations for the courses as early as possible since reservations must be closed when we reach 50 enrollments.

The text is being written at the present time by Helmut Thielsch, the well-known expert on industrial piping. The Course Committee were of the opinion that Industrial Piping is one of the most important courses we could give since it plays such a major part in so many operations. The tentative outline is as follows:

Monday

A.M. Fundamentals and General Principles
P.M. Materials and Processes

Tuesday

A.M. Low Alloy Steels
P.M. Stainless Steels

Wednesday

A.M. Aluminum and Titanium
P.M. Copper and Nickel Alloys

Thursday

A.M. Joint Design
P.M. Piping for Nuclear Operations

Friday

A.M. Common Defects Associated with Piping

New AWS Film

Some time ago the Milwaukee Section developed a TV program to show the public what welding means, the types of products that are welded and the opportunities in the welding industry. The commentary was done by Jack Chyle, past president of the SOCIETY, and it was decided to have a kinescope made in order that other Sections might have a pattern for similar operations.

The new film has just come to hand and it will be made available to Sections who would like to show it at their Section meetings. The title is "Careers, Welding Engineer, Opportunities in the Welding Industry."

When requesting use of the film, it will probably be easier to request the use of the "Opportunities" film. The film runs about 20 minutes.

Planning Manual

The Planning Manual for National Welded Products Month is now in the hands of Publicity Chairmen. Intensive planning should start this month in order that committees can be arranged and schedules prepared for the various activities which should take place to publicize this event.

We are expecting a record number of proclamations from mayors and governors this year. Each year this project has snowballed, and we receive publicity clips from newspapers and periodicals all over the country.

Any publicity chairman who has not received his Planning Manual should get in touch with the Information Department at headquarters without delay.

Section educational chairmen and publicity chairmen should also have received a new publication from the Department of Information and Education. This little text is the result of the Open Meeting in Pittsburgh and is full of very interesting information on how to conduct a course and how to conduct a seminar. This handy little booklet should be kept by you as a reference when planning many of your activities.

It is hoped that such material can be made available to Sections periodically in order that news on education, publicity and such items can be circulated.

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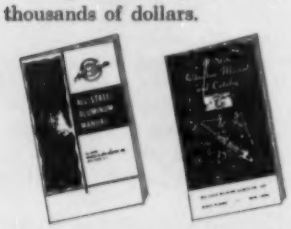

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CONDUCT SUCCESSFUL PROGRAM

Educational Activities Committee of the Chicago Section.
Standing (left to right): W. Good, Bill Craske, A. R. Meyer, E. J. Zahumensky.
Seated: R. E. Oller, E. J. Hemzy, R. F. La Bounty (Chairman), E. Silvers

Chicago Section Holds Educational Series

The Chicago Section has just concluded a highly successful education series. Running on Thursdays between 7:00 and 9:00 P.M., the course began on September 22nd and finished October 20th.

The program was divided into five sections and was held at the Chicago Bridge and Iron Dome. We understand that the lectures were very enthusiastically received and over 200 people attended.

The Chicago Section, and particularly the Educational Activity Committee of the Chicago Section, under R. L. La Bounty, are to be congratulated. There is a tremendous amount of work attached to presenting these courses and their justification is the fact that they widen the field of welding to include people who would not otherwise have the opportunity of learning the fundamentals of our industry.

AWS DIRECTORS-AT-LARGE

Term Expires	1961	1962	1963
	A. A. Holzbaur	Jay Bland	R. B. McCauley
	D. B. Howard	F. G. Singleton	John Mikulak
	J. L. York	C. B. Smith	E. F. Nippes
	W. H. Hobart, Jr.	J. R. Stitt	R. D. Stout

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		District No. 11•Northwest	C. B. Robinson

AWS PAST-PRESIDENT DIRECTORS

C. I. MacGuffie G. O. Hoglund

UNITED ENGINEERING CENTER

Progress report shows that while construction is on schedule, contributions are lagging

Starting the New Year right, several new sections appear on the Honor Roll. Even so, AWS contributions stand at 56% of goal.

Honor Sections

Section	Goal, %	Section	Goal, %
Oklahoma City	125	Eastern Illinois	100
Mahoning Valley	113	Holston Valley	100
Hartford	104	Long Beach	100
Kansas City	102	Louisville	100
N. E. Tennessee	102	New Hampshire	100
Puget Sound	102	N. Central Ohio	100
Tulsa	102	North Texas	100
Baton Rouge	101	Northern N.Y.	100
Colorado	101	Olean-Bradford	100
Detroit	101	Pascagoula	100
Niagara Frontier	101	San Antonio	100
Providence	101	Sangamon Valley	100
Rochester	101	Santa Clara Valley	100
St. Louis	101	Syracuse	100
Birmingham	100	Toledo	100
Boston	100	Western Mass.	100
Bridgeport	100	Wichita	100
Chattanooga	100	Worcester	100
Dayton	100		

Pledges Needed to Meet Goal

Section	Needed	Section	Needed
Philadelphia	56	Richmond	400
Mohawk Valley	100	Western Michigan	400
Tri-Cities	100	Cincinnati	416
Nashville	145	York-Central Pa.	435
Albuquerque	150	Saginaw Valley	460
Anthony Wayne	150	Salt Lake City	480
Shreveport	195	Portland	485
Arizona	200	Indiana	490
Nebraska	200	Stark Central	495
Maryland	215	Fox Valley	500
New York	218	Washington, D. C.	500
Carolina	245	Lehigh Valley	725
San Diego	250	Columbus	790
Northwestern Pa.	280	Long Island	800
J. A. K.	295	Northwest	822
Iowa	300	Milwaukee	977
Michiana	300	San Francisco	1154
Mobile	300	New Jersey	1460
Peoria	340	Houston (and Sabine)	1540
Susquehanna Valley	355	Chicago	1640
Iowa-Illinois	370	Pittsburgh	2168
New Orleans	390	Cleveland	2355
South Florida	395	Los Angeles	2825
Madison-Beloit	400		

With construction proceeding according to schedule, the Engineering Center is due for completion by mid-1961. The time is drawing near when AWS will have to pack up and move. When that time comes, it would be no more than fitting to expect that AWS will have shouldered its share of the burden along with its partners.

What is this share? Relatively speaking it is not large. The total cost of the building is estimated at $12,560,000. Of this amount about 27% will be realized from the sale of the old property on 39th St. Industry has already responded generously by meeting its quota of 43% of the cost. The remaining 30% amounting to $3,800,000 is the quota of the participating societies. AWS has assumed $60,000 of this amount as its share—less than $1/2$ of 1% of the total. Membership-wise this is a relatively small figure. Considering the over-all advantages of the new Center, it is a bargain.

Construction on the United Engineering Center had reached this point on Nov. 3, 1960. Rising walls enclose the structure as stainless steel mullions reach to the 9th floor and the limestone facing, seen at the rear, is at the beginning of the 16th

TECHNICAL PAPERS SESSIONS

1961

AWS 42ND ANNUAL MEETING and AIEE ELECTRIC WELDING CONFERENCE

APRIL 17-21 • HOTEL COMMODORE, NEW YORK CITY

REGISTRATION

MEZZANINE FLOOR
HOTEL COMMODORE

Sunday, April 16 • 3:00 P.M. to 6:00 P.M.
Monday, April 17 • 8:00 A.M. to 4:00 P.M.
Tuesday, April 18 • 8:00 A.M. to 4:00 P.M.
Wednesday, April 19 • 8:30 A.M. to 4:00 P.M.
Thursday, April 20 • 8:30 A.M. to 3:00 P.M.
Friday, April 21 • 8:30 A.M. to 11:00 A.M.

The following schedule of technical papers is not necessarily final. A more complete and detailed program, including an account of other activities, will be published in the April issue of the WELDING JOURNAL.

WELDING SHOW EXHIBITS AND DEMONSTRATIONS
NEW YORK COLISEUM

Hours of the Exposition: Tuesday, April 18 • 10:00 A.M. to 10:00 P.M.
Wednesday, April 19 • 10:00 A.M. to 10:00 P.M.
Thursday, April 20 • 10:00 A.M. to 6:00 P.M.

Admission by Registration

APRIL 17, MONDAY MORNING

10:00 A.M.—Official Opening and Business Session

CHAIRMAN—J. E. Dato, Linde Company

ADDRESS—R. D. Thomas, Jr., President, AWS

NATIONAL AWARDS

ADAMS LECTURE—Studies on Cracking of and Transformation in Steels During Welding, by H. Granjon, Institut de Soudure, France

APRIL 17, MONDAY AFTERNOON THREE SIMULTANEOUS SESSIONS, 2:00 P.M.

Papers "A" Start at 2:00 P.M.
Papers "B" Start at 2:50 P.M.
Papers "C" Start at 3:40 P.M.

1. Processes

(SPONSORED BY INTERNATIONAL INSTITUTE OF WELDING)

A. Notes on the Appreciation of Brazing Filler Metals and Fluxes
by C. G. Keel, Switzerland, G. M. A. Blanc, Switzerland, and J. Colbus, West Germany

B. Gas Mixtures in Shielded-arc Welding with Consumable Electrode
by M. M. Komers, West Germany, and L. Wolff, West Germany

C. The Solutions Adopted in Some Difficult Applications of Flash Welding
by M. E. Bylin, Sweden

2. Welded Structures

A. Modern Welded Design of Multistory Structures
by Omer W. Blodgett, The Lincoln Electric Co.

B. Fatigue Behavior of Welded Joints in Reinforcing Bars for Concrete
by W. W. Sanders, Jr., P. G. Hoadley and W. H. Munse, University of Illinois

C. Residual Stresses in Welded Plates
by N. R. Nagaraja Rao and Lambert Tall, Lehigh University

3. Alloy Fabrication

A. Fusion and Resistance Welding of Columbium Alloys
by W. R. Young, General Electric Co.

B. Heat Treatment and Welding Characteristics of B120VCA Titanium-alloy Sheet
by John F. Rudy, Frank A. Crossley and Harry Schwartzbart, Armour Research Foundation

C. Welded Rocket Cases are Reliable at 200,000 Psi Yield Strength
by E. J. Wilson, Jr., Redstone Arsenal

APRIL 17, MONDAY AFTERNOON

4:30 to 6:00 P.M.

Educational Lecture Series (Part I)

Heat Sources, Heat Flow and Heat Effects in Welding
by N. N. Rykalin, USSR

CHAIRMAN
E. C. Miller, Union Carbide Nuclear Co.

CO-CHAIRMAN
To be appointed later

APRIL 18, TUESDAY MORNING THREE SIMULTANEOUS SESSIONS, 9:30 A.M.

Papers "A" Start at 9:30 A.M.
Papers "B" Start at 10:20 A.M.
Papers "C" Start at 11:10 A.M.

4. Resistance Welding

(SPONSORED BY A.I.E.E. ELECTRIC WELDING COMMITTEE)

A. Applying Static Control to Resistance Welding
by C. F. Meyer and W. J. Brown, Square D. Co.

B. Instrumentation in Automotive Resistance Welding
by Edward J. Zulinski, The Ford Motor Co.

C. Load Control for Resistance Welding
by R. E. Rogers, Instrument Control Co.

5. Brazing

A. Grain-boundary Penetration and Base Metal Erosion in High-temperature Brazing
by Nikolajs Bredzs and Harry Schwartzbart, Armour Research Foundation

B. Brazing Ultra-high Strength Steel for Missiles
by Melvin J. Albom and R. E. Anderson, Aerojet General Corp.

C. Brazing of Sandwich Structures of Columbium Alloys
by Mel M. Schwartz, Martin Co.

6. Arc Welding

A. Dip-transfer Welding of High-pressure Pipe
by W. W. Walker, Air Reduction Sales Co.

B. Automatic Arc-welding Process for Field Welding Steel Pipelines
by J. H. Nelson, G. E. Faulkner and P. J. Rieppel, Battelle Memorial Institute, and H. C. Cook, Esso Research and Engineering Co.

C. Semiautomatic vapor-shielded Welding: A New Process
by R. A. Wilson, The Lincoln Electric Co.

APRIL 18, TUESDAY AFTERNOON THREE SIMULTANEOUS SESSIONS, 2:00 P.M.

Papers "A" Start at 2:00 P.M.
Papers "B" Start at 2:50 P.M.
Papers "C" Start at 3:40 P.M.

7. Arc Welding

(SPONSORED BY A.I.E.E. ELECTRIC WELDING COMMITTEE)

A. Electrical and Metallurgical Factors Influencing Welding-arc Stability
by Jerry E. Ginn, Boeing Airplane Co.

B. Wave Shape Effect on Alloying and Arc Stability of Alternating Current Tungsten Inert-arc Welding
by Thomas B. Correy, General Electric Co.

C. Some New Concepts in Power Supplies and Arc Initiation Applied to TIG Spot Welding
by Marcel Sommeria, Sciaky Bros., Inc.

8. Brazing

A. Exothermic Brazing
by Roger A. Long, Narmco Industries Inc.

B. Argon Brazing of Difficult-to-braze Metals
by J. W. Hill, Linde Company

C. Eutectic Brazing of Zircaloy-2 to Type 304 Stainless Steel
by W. A. Owczarski, General Electric Co.

9. Applications

A. A Welded, Tubular-bucketed Turbine Wheel
by E. J. Clark, General Electric Co.

B. New Method of Backing Double-V Weld Joints in Steel Plate
by J. N. Cordea, R. M. Evans and P. J. Rieppel, Battelle Memorial Institute

C. Creative Architectural Design with Welded Space Structures
by M. P. Korn, Consulting Engineer

APRIL 18, TUESDAY AFTERNOON

4:30 to 6:00 P.M.

Educational Lecture Series (Part II)

Heat Sources, Heat Flow and Heat Effects in Welding
by N. N. Rykalin, USSR

CHAIRMAN
E. C. Miller, Union Carbide Nuclear Co.

CO-CHAIRMAN
To be appointed later

APRIL 19, WEDNESDAY MORNING TWO SIMULTANEOUS SESSIONS, 9:30 A.M.

Papers "A" Start at 9:30 A.M.
Papers "B" Start at 10:20 A.M.
Papers "C" Start at 11:10 A.M.

10. Welded Structures

(SPONSORED BY INTERNATIONAL INSTITUTE OF WELDING)

A. Determination of the Fatigue Limit by Means of a Single Welded Specimen or Assembly
by M. R. Cazaud, France

B. The Calculation of Welded Connections
by A. Van Douwen, The Netherlands

C. Pressure Vessel Design Requirements in the Future
by W. B. Carlson, United Kingdom

11. Arc Welding

(SPONSORED BY A.I.E.E. ELECTRIC WELDING COMMITTEE)

A. A Double-taper Tungsten-arc Welding Control
by Austin Dixon, Westinghouse Electric Corp.

B. Special Equipment for Low-current Metal-arc Welding
by W. J. Greene, A. Lesnewich and N. E. Anderson, Air Reduction Co.

C. Development of a Power Supply for Stored-energy Arc Welding
by Cecil C. Stone and Robert A. Noland, Argonne National Laboratory

APRIL 19, WEDNESDAY AFTERNOON TWO SIMULTANEOUS SESSIONS, 2:00 P.M.

Papers "A" Start at 2:00 P.M.
Papers "B" Start at 2:50 P.M.
Papers "C" Start at 3:40 P.M.

12. Weldability

(SPONSORED BY INTERNATIONAL INSTITUTE OF WELDING)

A. The Role of Hydrogen in Arc Welding with Covered Electrodes
by N. Christensen, Norway

B. Influence of Residual Stresses and Metallurgical Changes on Low-stress Brittle Fractures in Welded Steel Plates
by A. A. Wells, United Kingdom

C. Inspection and Measurements of Properties of Welds on Plastics
by G. A. Homes, Belgium

13. Resistance Welding

A. Fatigue Testing Resistance-spot Welds in Shear
by E. E. Weismantel and D. S. Kalbfleisch, The Budd Co.

B. Properties of Flash-welded Molybdenum
by E. G. Thompson and H. Binder, The Marquardt Corp., and H. Collins, Dresser Manufacturing Div.

C. Inserted-shim Projection Welding of a Continuous Rod Mat
by Keh-Chang Wu and R. E. Lewis, Watervliet Arsenal

APRIL 19, WEDNESDAY AFTERNOON

2:00 to 4:00 P.M.

Missiles and Rockets Welded Fabrication

MODERATOR

D. B. Howard, ACF Industries, Inc.

PANELISTS

D. W. Kinsey, U. S. Steel Corp.
R. D. Libert, A. O. Smith Corp.
J. W. Jakubowski, General Electric Co.
J. F. Rudy, Armour Research Foundation

APRIL 20, THURSDAY MORNING THREE SIMULTANEOUS SESSIONS, 9:30 A.M.

Papers "A" Start at 9:30 A.M.
Papers "B" Start at 10:20 A.M.
Papers "C" Start at 11:10 A.M.

14. Electroslag Welding

A. Electroslag Welding in West European Countries—Improvement and Applications
by F. G. Danhier, Belgium

B and C. Electroslag Welding of Very Thick Materials
by B. E. Paton, USSR

15. Research and Weldability

A. A New Technique for Studying Residual Stresses
by D. C. Martin and Koichi Masubuchi, Battelle Memorial Institute

B. The Cruciform Test for Plate-cracking Susceptibility, II
by W. P. Hatch, Jr., Watertown Arsenal Laboratories, and L. E. Poteat, North Carolina State College

C. Hydrogen and Delayed Cracking in Steel Weldments
by E. P. Beachum, Bethlehem Steel Co., H. H. Johnson, Cornell University, and R. D. Stout, Lehigh University

16. Arc-spot Welding

A. Consumable-electrode Spot Welding
by J. A. Howery and G. F. Mack, National Cylinder Gas Co.

B. Gas-shielded-arc Consumable-electrode Spot Welding in Industry
by R. P. Sullivan, Linde Company

C. Semiautomatic Tungsten-arc Spot Welding of Stainless Steels and High-temperature Alloys
by R. J. Campbell and D. R. Miller, General Electric Co.

APRIL 20, THURSDAY AFTERNOON TWO SIMULTANEOUS SESSIONS, 2:00 P.M.

Papers "A" Start at 2:00 P.M.
Papers "B" Start at 2:50 P.M.
Papers "C" Start at 3:40 P.M.

17. Processes

A. New Concepts for Oxygen Cutting
by C. C. Anthes, Linde Company

B. Advances in Electron-beam Welding Techniques
by Robert R. Banks, Air Reduction Sales Co.

C. Ultrasonic Welding, Engineering, Manufacturing and Quality Control Problems
by J. Koziarski, The Martin Co.

18. Nuclear Components

A. Inconel Deposited Weld Metal for Nuclear-component Parts
by R. W. Minga and W. H. Richardson, Combustion Engineering, Inc.

B. Insulation Attachment by Welding for an Aircraft Nuclear Propulsion Powerplant
by R. J. Campbell and T. D. McLay, General Electric Co.

C. The Brazing of Graphite
by R. G. Donnelly and G. M. Slaughter, Oak Ridge National Laboratory

19. Research and Weldability

A. Transition-temperature Correlations in Constructional Alloy Steels
by G. M. Orner and C. E. Hartbower, Watertown Arsenal Laboratories

B. The Yield Strength of E9018 Weld Metal
by W. L. Wilcox and H. C. Campbell, Arcos Corp.

C. Ferritic Welding of Steel Armor
by Z. J. Fabrykowski, U. S. Army Ordnance Tank-Automotive Command

APRIL 21, FRIDAY MORNING THREE SIMULTANEOUS SESSIONS, 9:30 A.M.

Papers "A" Start at 9:30 P.M.
Papers "B" Start at 10:20 A.M.
Papers "C" Start at 11:10 A.M.

20. Submerged-arc Welding

A. Observations on Electrode-melting Rates during Submerged-arc Welding
by Michael H. Robinson, ACF Industries, Inc.

B. Advancements in Submerged-arc Welding of High-impact Steels
by R. A. Kubli and W. B. Sharav, Linde Company

C. Flux and Filler-wire Developments for Submerged-arc Welding HY-80 Steel
by Wallace J. Lewis, G. E. Faulkner and P. J. Rieppel, Battelle Memorial Institute

21. Gas-shielded Welding

A. Some Metallurgical Aspects of CO_2-shielded Arc Welding
by M. D. Randall and P. J. Rieppel, Battelle Memorial Institute

B. Argon-shielded Alternating-current Metal-arc Welding
by C. R. Sibley, Air Reduction Sales Co.

C. CO_2-shielded Welding Horizontal Joints of Oil Storage Tanks
by Paul W. Turner, Union Carbide Nuclear Co.

22. Research and Weldability

A. Welding of 12% Chromium Martensitic Stainless Steels
by C. H. Kreischer, A. E. Near and J. Cothren, General Electric Co.

B. Lime-coated Versus Titania-coated Stainless-Steel Electrodes
by B. S. Payne, Jr., G. J. Dormer and L. R. Haslip, Pfaudler-Permutit, Inc.

C. Effects of Repeated Repair Welding of Two Aluminum Alloys
by F. G. Nelson, Aluminum Co. of America

SECTION NEWS AND EVENTS

As reported to Catherine M. O'Leary

Alabama

ALLOY STEEL

Birmingham—The November meeting of the 1960–61 season of the *Birmingham* Section was held at Salem's Restaurant Number Two on Tuesday, November 8th. Even though this was election night, a large crowd turned out to greet two of our national officers.

Secretary Fred Plummer brought the Section up to date on national activities. He also expressed appreciation to the Section for the check which was presented to him and the pledge which has been made to meet the goal established for the United Engineering Center Drive.

President R. D. Thomas Jr., who is also president of Arcos Corp., made a most interesting talk on "Some Dramatic Applications of Stainless and Low-alloy Steel Welding." He showed a series of slides concerning the important part which stainless and low-alloy steels are playing in our missile and atomic power programs. The problems of welding these steels were discussed, and solutions were given for manual-arc and submerged-arc welding material all the way up through very thick sections.

MISSILES

Huntsville—The first regular meeting of the *Huntsville* Section was held at the Officers Club at the Redstone Arsenal on Thursday evening, October 27th.

Speaker for the evening was William F. Graves from the Army Rocket and Guided Missile Agency. He presented an unusually interesting talk entitled, "The Nike-Zeus System." This excellent presentation was followed by a short movie showing some of the potential capabilities of this antimissile missile.

California

BRAZING RESEARCH

Los Angeles—Highlighting the program for the October 20th meeting of the *Los Angeles* Section was Robert C. Bertossa, technical director for the Pyromet Co. of San Carlos, Calif. His subject was "Brazing Research on Missile Materials." Approximately 87 members and guesta turned out to hear Mr. Bertossa's technical presentation, 26 of these being from the North American Rocketdyne plant in Canoga Park where a considerable amount of high-temperature brazing is being accomplished. He is credited with the development of the patented "Horton-clad" vacuum-pressure cladding process. He explained this process and the necessary precautions required in making the perfect bond. The lecture also covered, with the use of slides, the joining of Rene 41, Inconel X, A-286, molybdenum, tantalum, columbium and tungsten. Brazing of the refractory metals held the interest of many and resulted in numerous questions on the process.

AUTHORS TALK

Sacramento Division was scene for talk by John Bartley (left) and Robert Frala (right) on September 28th

LOS ANGELES GATHERS FOR GUEST SPEAKER

Few of the many Los Angeles section members and guests who met on October 20th

R. C. Bertossa who spoke on "Brazing Research in Missile Materials"

BRAZING ALLOYS

Lemon Grove—The *San Diego* Section held a joint dinner meeting with the ASM on October 19th at the El Morocco in Lemon Grove.

Program Chairman Bob Manary introduced the speaker, A. T. Cape of Coast Metals, Inc. Mr. Cape showed slides and gave a talk on "Recent Developments in Brazing Alloys for Use at High Temperatures."

ELECTRON BEAM WELDING

San Diego—The November 16th meeting of the *San Diego* Section was held at the Midway Chuck Wagon Restaurant with 54 at dinner and 68 at the meeting which followed.

SECTION MEETING CALENDAR

FEBRUARY 1

SUSQUEHANNA VALLEY Section. Foot Hills Manor, Shickshinny, Pa., Dinner 6:45 P.M. "Fundamentals of the Oxygen Cutting Process," Joseph F. Kiernan, Air Reduction Sales Co.

FEBRUARY 2

NORTH CENTRAL OHIO Section. Plant Tour.

NORTHERN NEW YORK Section. Hot Shoppes, Route 9, Albany, N. Y., Dinner 7:00 P.M. Technical Session 8:00 P.M., "Welding and Brazing of Nuclear Fuel Elements," Pete Patriarca, Oak Ridge National Lab.

FEBRUARY 6

LEHIGH VALLEY Section. Walp's Restaurant, Allentown, Pa., Dinner 6:30 Technical Session 8:00 P.M., National Officers Night, "Some Dramatic Application of Stainless and Low-Alloy Steel Welding," R. D. Thomas, Arcos Corp.

FEBRUARY 7

TULSA Section. Stauffers Recreation Center. Joint Meeting ASM and ASME. "Design for Welding," Omer Blodgett, Lincoln Electric Co.

FEBRUARY 8

OKLAHOMA CITY Section. Dinner 6:30 P.M., Meeting 7:30, Cattleman's Cafe, Oklahoma City. "Welding Design as Related to Structural Fabrication," O. W. Blodgett, Lincoln Electric Co.

FEBRUARY 9

IOWA-ILLINOIS Section. Highland Park Bowl, Moline, Ill., Dinner 6:30 P.M., Meeting 7:30 P.M., "Welding Engineering in Engineering Education," R. B. McCauley, Ohio State University

J.A.K. Section. Joliet, "Cored Wire Electrode," Speaker from Lincoln Electric Co.

PUGET SOUND Section. "Recent Developments in the Field of CO_2 Welding," Stephen A. Yasko, Westinghouse Electric Corp., Welding Division.

ST. LOUIS Section. Ruggeri's Restaurant. "Insulation of Gulf Pipe Lines," James M. Shilstone, Shilstone Lab.

FEBRUARY 10

COLUMBUS Section. "Welding Power Sources," G. Willecke.

FEBRUARY 13

BOSTON Section. Hotel Bostonian. Dinner 6:00. "Some Dramatic Applications of Stainless Steel and Low-alloy Welding," R. D. Thomas, Jr., Arcos Corp.

NORTHWEST Section. Minneapolis, Minn., "Recent Developments in Aluminum Welding,"

FEBRUARY 14

BIRMINGHAM Section "It Isn't Mud," H. F. Reid, McKay Co.

DAYTON Section. To be announced.

NORTHEAST TENNESSEE Section. "Micro-Wire Welding," John Headapohl, Hobart Brothers Co.

SANGAMON VALLEY Section. Springfield, Ill., "Why Welds Fail," Helmut Thielsch, Grinnell Co.

WESTERN MASS. Section. Oaks Inn, Springfield, Mass., Dinner 6:30, Technical Session 8:00. "Welding Aluminum—Past, Present, Future," Ivan MacArthur, Olin Mathieson Chemical Corp.

FEBRUARY 15

HOUSTON Section. "Welding Stainless Steel," J. A. Goodford, Crucible Steel Co.

NORTHWESTERN PENNSYLVANIA Section. "It Isn't Mud," H. F. Reid, McKay Co.

PEORIA Section. Vonachen's Junction, "Power Sources for Gas Shielded Arc Welding Processes," A. Lesnewich, Air Reduction Co.

TOLEDO Section. Toledo Yacht Club, Dinner 6:30, Technical Session 7:45. "Fabrication and Welding of Clad Steels," L. K. Keay, Lukens Steel.

FEBRUARY 16

BATON ROUGE Section. "Control and Correction of Distortion in Steel Weldments," LaMotte Grover, Air Reduction Sales Co.

BEAUMONT Section. "Welding Stainless Steel," J. A. Goodford, Crucible Steel Co.

MADISON Section. Janesville, Wis. "Dramatic Applications of Stainless and Low-Alloy Steel Welding," R. D. Thomas, Jr., Arcos Corp., F. L. Plummer, AWS.

MAHONING VALLEY Section. Victoria Restaurant, Youngstown, Ohio, Dinner 7:00, Meeting 8:00. "Why Welds Fail," Helmut Thielsch, Grinnell Co.

MICHIANA Section. South Bend, Indiana. "Fundamentals of Gas Welding and Brazing."

FEBRUARY 17

FOX VALLEY Section. Appleton Elks Club, Appleton, Wis., 8:00 P.M., "Some Dramatic Applications of Stainless and Low-Alloy Steel Welding," R. D. Thomas, Jr., Arcos Corp., F. L. Plummer, AWS

MARYLAND Section. Engineers Club, Baltimore, Md., Dinner 6:30, Meeting 8:00. "Power Supplies for Arc Welding Processes," G. K. Willecke, Miller Electric Mfg. Co.

MILWAUKEE Section. Ambassador Hotel, 6:30 Buffet Dinner, 8:00 Technical Meeting. "Automatic Welding as a Tool of Production," J. D. Brown, Allis-Chalmers Manufacturing Co.

FEBRUARY 18

SAGINAW VALLEY Section. Rolling Green Country Club. Ladies' Night—Dinner Dance

FEBRUARY 20

HOUSTON Section. (Corpus Christi Div.) "Special Steel Fabrication Applications," L. F. Megow, Hahn and Clay.

PHILADELPHIA Section. Engineers Club, 8:00 P.M., "Plasma Arc as a Metal Processing Tool."

ROCHESTER Section. Liederkrantz Club. Dinner 7:00. Meeting 8:00. "Stainless Steel Welding," W. L. Wilcox, Arcos Corporation.

FEBRUARY 21

MOBILE Section. Korbet's Restaurant, 6:30 Social Hour, 7:15 Dinner, 8:00 Technical Session.

FEBRUARY 23

NIAGARA FRONTIER Section. The Cypress, Buffalo, N Y., "Safety in Welding."

FEBRUARY 24

INDIANA Section. Severin Hotel, Indianapolis, Ind., Valentine Party—Ladies' Night.

HOUSTON (AUSTIN DIV.) Section. Villa Capri Restaurant, "ASME and ASA Codes on Pipe Welding," Virgil Reed, Piping Industry Welding Service.

Editor's Note: Notices for April 1961 meetings must reach JOURNAL office prior to January 20th, so that they may be published in the March Calendar. Give full information concerning time, place, topic and speaker for each meeting.

After a short business meeting, the speaker for the evening was introduced as Bill Pierce of the Air Reduction Co. His subject, "Electron Beam Welding," was followed by a question-and-answer period.

WELDING ROCKET MOTORS

Rancho Cordova—The *Sacramento Division* met on September 28th at Cordova Lodge, Rancho Cordova. Speakers at this meeting were J. E. Bartley, production engineer, Linde Co. Their paper on the "Welding of Large Rocket Motors" was published in the December 1960 issue of the WELDING JOURNAL.

ELECTRON BEAM WELDING

Berkeley—Robert Stone of Air Reduction Co. was speaker at the October 24th meeting of the *San Francisco* Section. The meeting was held at Spenger's Fish Grotto in Berkeley.

Speaking on "Electron Beam Welding," Mr. Stone traced the history of this development, its fundamental factors, and described the three types of guns used. Following a description of the operation of the gun, its operational characteristics and welding procedures for various alloys, Mr. Stone concluded his talk by reviewing the metals now being welded. In doing so, he mentioned specific applications and speculated upon the future possibilities of the process. That his talk, illustrated with slides, was received with great interest was proved by the lengthy question-and-answer period which closed the meeting.

TALKS ON ELECTRON BEAM WELDING

Robert Stone was guest speaker at October 24th meeting of the San Francisco Section

Educational Course on "Fundamentals of the Welding Processes"

The *Santa Clara Valley* Section will conduct its 1961 annual series of educational lectures during the month of February. The general theme will be "Fundamentals of the Welding Processes." This series of lectures has been planned with the intended purpose of informing design engineers, supervisors, craftsmen and members of management with the actual application of the various welding processes being used throughout the welding industry.

The lecture series will be conducted at the San Jose State College in the Engineering Lecture Hall, Room E-118. The course will consist of five evening periods starting at 7:30 p.m. and ending at 10:00 p.m. Speakers well versed in their subject have accepted invitations to lecture during the series. A question period will be conducted at the end of each lecture to cover related problems.

There will be a small tuition fee for the course. AWS members $5.00; nonmembers $10.00 ($5.00 applicable to membership); students—college engineering majors and high school $1.00 (applicable toward student membership). There will be an appropriate certificate awarded to those who complete the course.

The dates, topics and speakers for the lecture series are as follows:

February 7th
"Fundamentals of Arc Welding Process," Edwin Olds, A. O. Smith Corp.

February 9th
"Fundamentals of Oxygen-Acetylene Process—Welding-Cutting," Fred Stettner, Victor Equipment Co.

February 14th
"Fundamentals of the Tungsten Inert-gas Process," Charles Robinson, Air Reduction Pacific Co.

"New Welding Processes," Thomas Hazlett, University of California, Berkeley

February 16th
"Fundamentals of Metal-arc Inert-gas Process," Ron Skow, Linde Co.

At the last meeting on February 16, there will also be a panel of qualified welding experts to discuss general questions in relation to the welding processes covered by the lecture series. The course has been planned to be of unusual interest and will be of decided benefit to those persons who are engaged in welding design, fabrication, construction, management, supervision or application.

SHOW AND CONFERENCE

San Jose—The *Santa Clara Valley* Section sponsored the Third Western Welding Show on Oct. 13, 14 and 15, 1960, which was held in the exposition building of the Santa Clara County Fair Grounds in San Jose. The Western Welding Technical Conference was also held in conjunction with the show in the St. Claire Hotel.

Welding Show Chairman A. C. Otto, Technical Conference Chairman J. W. Turner and their committees arranged and conducted this outstanding welding event in the Bay area. The show was attended by approximately 1500 welding-minded guests and visitors. Total paid registrations for the technical conference amounted to 232.

The "kick-off" luncheon was held in the Sparton Room of the St. Claire Hotel at noon on October 13th. Section Chairman W. R. Smith introduced Paul Moore, mayor of San Jose. The mayor welcomed the visitors and guests and then gave a short address on the major role that the welding industry is playing in the winning of the "cold war" and the importance of a strong industrial nation to the free world.

A chain cutting ceremony was held at the location of the show with the mayor officiating.

A total of 36 welding equipment and material manufacturers and suppliers exhibited products and equipment. A large number of live demonstrations of the latest welding equipment and supplies were shown. Special displays of local welded products were of interest to the visitors who had gathered from the 11 western states.

The Western Welding Technical Conference was also an outstanding event. Members from the various sections in District 11 added to the success of the conference by acting as co-chairmen of the morning and afternoon sessions. A great deal of new and interesting information dealing with welding and allied subjects was presented during the three-day conference. Local colleges and schools took good advantage of the welding show, with an estimated 250 visiting students attending the exhibit booths and displays.

District of Columbia

NATIONAL OFFICERS

Washington—The national pres-

CAROLINA CO-SPONSORS MAINTENANCE SHOW

Fred Dalton (left) talks to prospective AWS member in Carolina Section booth at Southwestern Show held September 14–16 in Raleigh, N. C.

ident and national secretary of the SOCIETY were guests of the *Washington* Section at their dinner meeting held on Thursday, September 15th, at the Hotel Ebbitt.

Secretary Fred L. Plummer spoke on the activities and plans of the SOCIETY. He explained the functions of the national headquarters and the role it plays in the propagation of the science of welding throughout the world.

President R. D. Thomas' talk dealt with the various application of stainless and low-alloy steels in the fabrication of pressure vessels and other highly stressed structures. He pointed out how technological developments in the fields of electrode design and processes have made possible present-day engineering structures.

NEW ASTM STRUCTURAL STEEL

Principal speaker for the South Florida Section in October was William Parker (right) who spoke on the new ASTM A36-60T structural steel for bridges, buildings and general structural use. The others with Mr. Parker are Perry Kennerk (left) and Harold Hose

ELECTRODE SECTION

Washington—The October meeting of the *Washington* Section was held on the 20th at the Washington Gas Light Co. Auditorium. Dinner at the Hotel Ebbitt preceded the meeting.

J. E. Hinkel, engineer from the Lincoln Electric Co., Cleveland, Ohio, talked on the selection of electrodes for mild steel welding. In his talk he brought out the different factors which govern electrode selection. Nine different AWS mild steel electrodes produce acceptable welds with very similar physical properties; however, each of these electrodes is best suited for a particular application. Electrode characteristics such as "fast freeze," "fast fill" and "freeze-fill," were explained together with how they govern the correct electrode selection. The talk was informative and well presented.

Florida

ASTM STRUCTURAL STEEL

Hialeah—Following a dinner at the Park Lane Cafeteria, the *South Florida* Section held its October meeting.

An interesting and informative talk on the new ASTM A36-60T improved structural steel for bridges, buildings and general structural use was presented by William Parker and Chuck Adams.

Mr. Parker, the principal speaker, is metallurgist for the Tennessee Coal and Iron Div., U. S. Steel Corp. Mr. Adams is the local representative.

Illinois

FLUX-CORED CO_2 WELDING

Danville—The regular meeting of the *Eastern Illinois* Section was held at Connor's Restaurant in Danville on October 26th. After dinner and during a short business meeting, Ralph Ross and Prof. Morse B. Singer were presented with past chairman pins, and Prof. Walter H. Bruckner of the University of Illinois was presented the Adams Memorial Membership Award.

A. F. Chouinard of the National Cylinder Gas Div., Chicago, and a national vice president of the SOCIETY, presented a technical discussion of the "Flux Cored CO_2 Welding Process," supplementing his talk with slides and movies. After describing some of the background of this process and tracing its development, Mr. Chouinard discussed the physical properties, applications and advantages of the process.

Indiana

ELECTRODE CLASSIFICATIONS

Ft. Wayne—Thirty-one members and guests attended the October 20th meeting of the *Anthony Wayne* Section held at Fab-Weld Inc., Ft. Wayne.

The meeting featured interpretation of electrode characteristics as

CALUMET AREA MEETING

Dr. G. E. Claussen illustrates point during talk at November 3rd Chicago Section meeting

NATIONAL MEMBERSHIP AWARD TO PROFESSOR

Adams Memorial Membership Award presentation to Prof. W. H. Bruckner, University of Illinois, at Oct. 26 meeting of Eastern Illinois Section. Left to right are: George Maney, L. L. Baugh, Prof. Bruckner, National Vice President A. F. Chouinard, and Evertt Morris

indicated by the AWS classification by actual demonstration.

D. B. Rice of the Sutton-Garten Co. acted as narrator. Demonstrations were by Kenneth Zimmerman and Lee Voght of the American Hoist and Derrick Co.

ARC-WELDING ELECTRODES

East Chicago—The *Chicago* Section sponsored a Calumet Area Meeting on November 3rd at which time Dr. G. E. Claussen of Arcrods Corp., Sparrows Point, Md., presented a talk on "Fundamentals of Arc Welding Electrodes." Dr. Claussen's talk covered various types of electrodes, coverings and applications. His audience consisted of 195 AWS members and guests from the heavy industrial area of Hammond, Gary, Whiting, East Chicago and the far South side of Chicago.

An excellent family style dinner of chicken and beef was served prior to the meeting at the Jockey Club Restaurant in East Chicago, Ind. The committee which planned the affair consisted of R. M. Kolb of the Standard Oil Co., E. J. Zahumensky of the Standard Railway Equipment Co. and A. G. Craske of Calumet Welding & Supply Co.

The excellent turnout shows the desire of the Calumet Area welding people to attend AMERICAN WELDING SOCIETY meetings when held in nearby locations. The numerous questions presented to Dr. Claussen indicated the tremendous interest of the audience in welding.

WELDING IN AUSTRALIA

Cumberland—The October meeting of the *Indiana* Section was held at Buckley's Restaurant in Cumberland on October 28th.

Following the dinner and recognition of members present, Section Director E. J. Gorde introduced the guest speaker, L. M. Klentz of the Taylor Winfield Corp. His subject, "Welding in Australia," covered observations made on a recent trip to that country and was illustrated by slides of various points of interest during his travel. No photographs of welding operations inside the plants were permitted, although the exterior of the plants of several American firms were shown. Despite the lag of Australian welding technology behind that of the United States, almost all of the conventional processes have been used for years there.

The speaker noted that 6000 miles of auto travel were required to visit 40 industrial plants, since most industrial activity is located along the coastal areas.

The presentation, although nontechnical in scope, was interesting and of general interest to the members.

ANTHONY WAYNE TALK AND DEMONSTRATON

Guest Speaker, D. B. Rice

Demonstration by Kenneth Zimmerman and Lee Voght

Iowa

COVERED ELECTRODES

Des Moines—Harry F. Reid, manager, Technical Sales Division of the McKay Co. discussed the "Development of Covered Arc-welding Electrodes" at the October 20th meeting of the *Iowa* Section held at the Hotel Kirkwood.

Using World War II as a breaking point, he told of the development of six or seven basic electrodes before the war. "Since the war," Mr. Reid said, "the manufacturers of electrodes have taken the welder's tools—electrodes—and modified them for special uses." This has meant a loss of skills by operators, Mr. Reid pointed out, by the advancement in electrode modification.

Mr. Reid spoke with a background as a chemist, as research engineer with Ceramics Division, Battelle Memorial Institute, where his work covered development of coverings for ferrous and nonferrous arc-welding electrodes.

Kansas

METAL-ARC WELDING

Wichita—The *Wichita* Section met on October 17th at the Stockyards Hotel. The 38 people attending enjoyed a semitechnical

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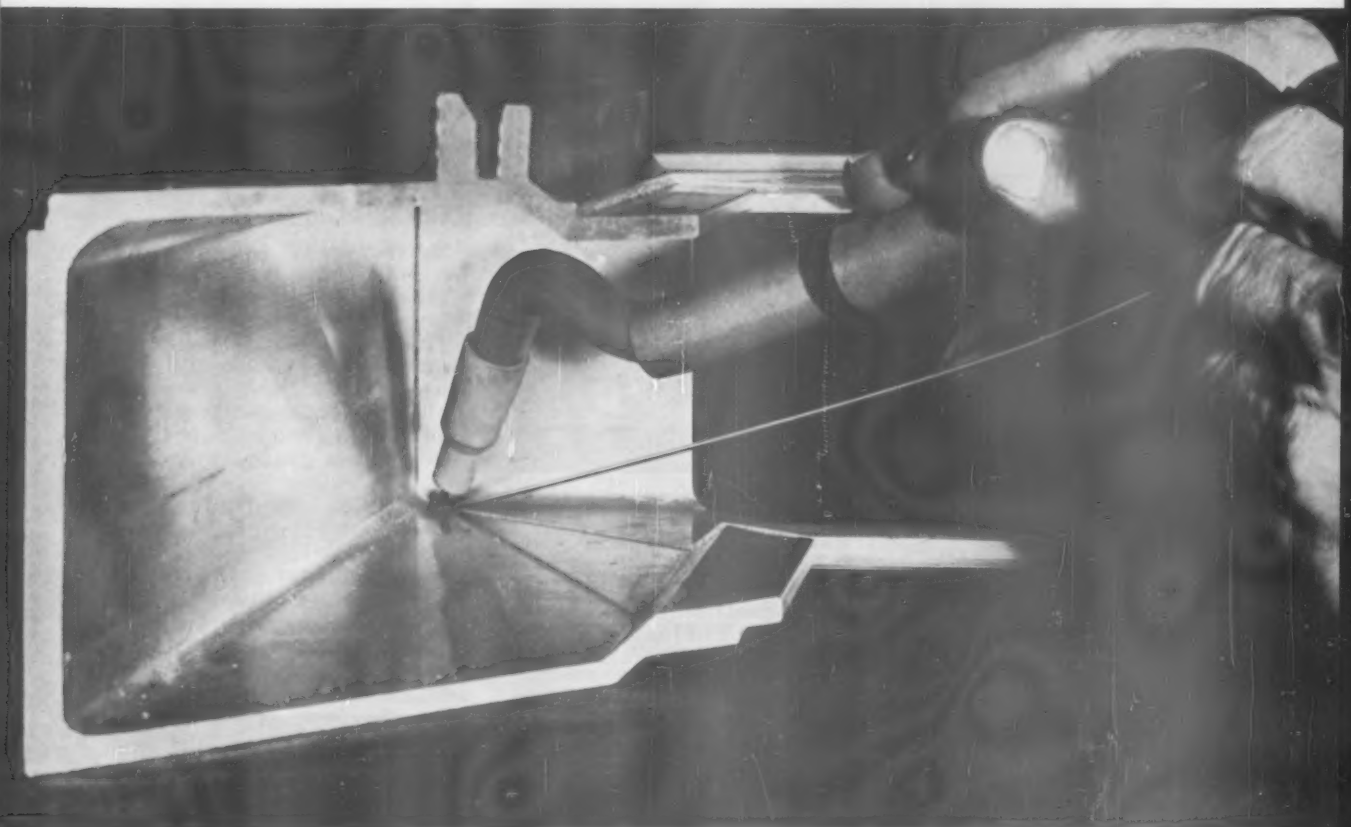

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BRAIN TRUST FOR WELDING SHOW

Wichita Section members of the coordinating team for the Kansas Welding Show meet to discuss plans. Left to right are: Jim Finke, Robert Clemens, Marcel Lampton, Murl Green, Wilmer Smith, Don Green and Wilbur Dent

report given by Harry D. Mann, who spoke on the subject "Gas-shielded Metal-arc Welding." Mr. Mann very effectively presented what progress has taken place in gaseous shielding of the arc over the past ten years. This presentation was aided by the use of slides and a motion picture film which described the new processes recently developed.

An informal dinner preceded the meeting.

NEW CONCEPTS

Wichita—The November meeting of the *Wichita* Section was held on November 17th at the Stockyards Hotel. The scheduled speaker, Thomas McElrath, passed away on November 6th.

In his place, Robert Telford, engineer with the Linde Co., Newark, N. J., presented to the group two major concepts of the inert-gas consumable-wire process. He described the pilot arc principle and showed slides and a motion picture on this process. He also described and showed slides and a film on the short-arc process.

The advantages and disadvantages of these relatively new processes were explained and followed by a question-and-answer discussion. The talk was enjoyed by an attendance of 50 members and guests.

TUNGSTEN-ARC DEVELOPMENT

Guest speaker R. T. Telford described the development of tungsten-arc welding at the November 17th meeting of the Wichita Section. Left to right are: W. C. Smith, Wichita Section Chairman; R. T. Telford; and W. M. Dent, vice chairman

Louisiana

METALLURGY

Baton Rouge—National Secretary Fred Plummer and National President R. D. Thomas, Jr., were the guest speakers at the October 6th dinner meeting of the *Baton Rouge* Section held at the Sherwood Forest Country Club.

Mr. Plummer discussed the worldwide scope of the AWS and its future. Mr. Thomas, as president of the Arcos Corp., presented "Some Dramatic Applications of Stainless and Alloy Welding."

The Section reports that the metallurgy course being offered at University College of Lousiana State University has had such tremendous success that members were turned away at registration due to the overwhelming numbers that showed interest in the program. Classes are 3 hr in length. The first class started Sept. 10th and will continue until Jan. 10, 1961. Thus far, the course has proved to be an asset to members attending, with excellent results expected.

BUILDING CONSTRUCTION

Baton Rouge—Omer Blodgett of The Lincoln Electric Co., Cleveland, Ohio, was the guest speaker at the November 3rd meeting of the *Baton Rouge* Section held at the Sherwood Forest Country Club. The topic of his talk was "Welded Building Construction." The talk was designed to be of special interest to architects, engineers, structural fabricators and erectors.

Mr. Blodgett is considered one of the outstanding technical speakers on this subject. He discussed current construction of all-welded buildings with particular attention to the best way of doing a job and how to take full advantage of savings in time and weight using welding.

Slides were shown on the present methods of fabrication of steel prior to erection and of buildings being erected.

Maryland

HARD SURFACING

Baltimore—The *Maryland* Section held their regular monthly meeting on October 21st at the Engineers Club in Baltimore.

There were 27 members and guests present for dinner. This was followed by the showing of a film on the highlights of the 1959 football season of the Champion Colts. This film was greatly enjoyed by all.

There were 52 members and guests present for the technical meeting. Elden C. Hurt of the Haynes Stellite Co. gave a talk on mechanized hard surfacing. He also showed film of several applications and explained how each was adapted to mechanization.

Massachusetts

OXYACETYLENE

Springfield—The *Western Massachusetts* Section was host to the Connecticut Valley Chapter of the American Society of Safety Engineers at a meeting held in the Oaks Inn on November 8th.

Seventy-eight members and guests enjoyed a fine pot roast dinner, after which Paul V. Croteau of the Smith Welding Equipment Co., Minneapolis, Minn., kept the attention of the group with his talk on "Safety of Gas Welding and Cutting Equipment." Mr. Croteau demonstrated the right and wrong methods of using this type of equipment.

The objective of his talk was to better understand safe practices as they pertain to oxyacetylene welding and cutting equipment. The following are examples of safety rules which he suggested: use no oil; blow off cylinder valve before attaching regulator; open

SPEAKER GREETED

Guest Speaker John L. Lang is greeted by Worcester Section officers. Left to right are: J. Belisle, John Lang, U. S. N. Caranchini and E. Spellman

cylinder valve slowly; release regulator adjusting screw; purge both oxygen and acetylene lines; ignite acetylene before opening oxygen valve; do not compress acetylene to more than 15 psi; stand aside from regulator when you open cylinder valve; do not use compressed oxygen for compressed air; keep heat, spark and flames away from combustibles.

While this meeting took place on Election Day and everyone was anxious to find out the results, all agreed that this meeting was worthwhile and would not have missed it.

LARGE WELDMENTS

Worcester—Thirty members and guests of the *Worcester* Section enjoyed a most interesting coverage of "Large Weldment Fabrications" as given by John L. Lang of the Lukens Steel Co., Coatesville, Pa., at their meeting held on October 10th at Nicks Grill in Worcester. Mr. Lang's enthusiastic answers to questions makes him a most welcome guest.

Michigan

NATIONAL OFFICERS

Detroit—The *Detroit* Section entertained President R. D. Thomas and National Secretary Fred L. Plummer in typical "Dynamic Detroit" fashion on November 11th—pickup at the airport; stop enroute to the hotel at Greenfield Village to view an exact working duplicate of Prof. Elihu Thomson's original resistance welding machine; press interview and television pictures taken with the Thomson machine in operation; dinner at the Detroit Engineering Society with Mr. Thomas and Plummer both giving talks and finally a special meeting of the Section's Executive Board, mixing cocktails and business.

At the meeting, Mr. Plummer, was presented with the Section's final contribution toward the new building, which adds the Section to the list of those completing their pledge. Mr. Plummer enlightened us on the progress of the new building on changes in the National Staff, and changes in the JOURNAL, new specifications, vocational training, our Handbook program, membership and Annual Meetings.

R. D. Thomas, Jr., who is also president of the Arcos Corp., presented an extremely interesting discourse entitled "Some Dramatic Applications of Stainless and Low-alloy Steel Welding." Mr. Thomas' remarks centered around the "Constitution Diagram for Stainless Steel Weld Metal" by Anton L. Schaeffer. Among other items discussed by Mr. Thomas were the use of the EB inserts and problems encountered in the welding of our submarine shells.

GIFT FROM SAGINAW

Herman Werschky (left) presents token of appreciation to John Headapohl, guest speaker on November 3rd

AUTOMATIC WELDING

Saginaw—Eighty-one members and guests of the *Saginaw Valley* Section were present on November 3rd at the High Life Inn for dinner and meeting.

Guest speaker was John H. Headapohl, manager of the Automatic Welding Div., Hobart Brothers Co., Troy, Ohio. He discussed the submerged-arc, inert-gas and carbon dioxide welding processes with emphasis on the carbon dioxide process. The talk was supplemented by slides showing data and welding installations and included a discussion of constant voltage type power sources.

As usual, a large percentage of members turned out for the meeting. Section Chairman Chuck Moelenaar claimed the Saginaw Valley Section had a higher percentage of membership attending each regular meeting than any other Section in the SOCIETY. This claim is backed up by the wager of a bag of the finest Michigan beans, against a comparable local product of any other Section. Floyd J. Zdrojkowski of Saginaw Steering Gear, has been appointed chairman of the "Bean Challenge Committee," and will endeavor to extend this challenge directly to each section chairman. Secretary Fred Plummer has consented to act as one of the judges for this contest.

DETROIT SEES MUSEUM PIECE IN ACTION

Members of Detroit Section, along with AWS President R. D. Thomas, Jr. (far right), watch Professor Thomson demonstrate a duplicate of his original resistance welding machine

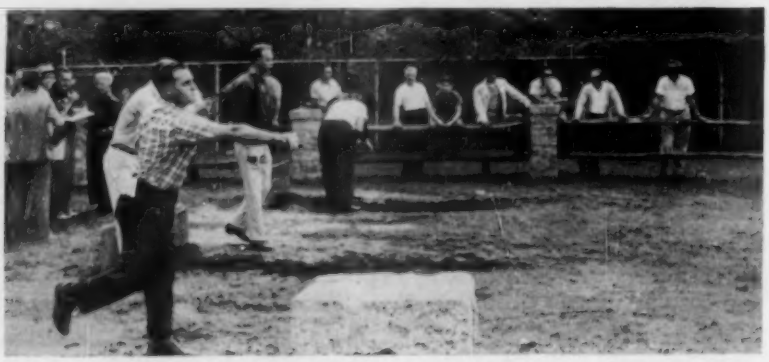
Minnesota

WELDING SEMINAR

Minneapolis—On November 5th, the *Northwest* Section, in cooperation with the University of Minnesota, sponsored a one-day seminar on "Identification and Pre-

NEW JERSEY AT WORK AND PLAY

New Jersey Section members listening to Dr. R. D. Stout on October 18th



Horseshoe pitching at Annual Picnic on September 18th attended by 840 AWS members and friends

vention of Metal Failures in Welding" at the Center for Continuation Study at the University.

Seventy-five members and guests heard an outstanding discussion of the problem by Prof. Fulton Holtby, associate professor, mechanical engineeering, University of Minnesota; John Mikulak, assistant to the vice president, Worthington Corp.; John P. Battema, project manager, Phillips Electronics; and R. P. Sopher, supervisor of Research Metallurgy, Electric Boat Division of General Dynamics.

John Schmitt and Jack Barckhoff of the Northwest Section organized the program and acted as chairmen for the sessions.

Section Chairman N. C. Qualey presided over a spirited question-and-answer period, following the formal presentations.

A regular monthly evening meeting followed the Seminar.

Nebraska

VOCATIONAL EDUCATION

Milford—The *Nebraska* Section held its monthly meeting on the campus of the Nebraska Vocational Technical School at Milford on October 14th. A buffet dinner was served to the group by the cafeteria staff. Al Havener, school staff member and Section vice chairman, introduced the speaker for the evening, Cecil E. Stanley.

Mr. Stanley, assistant state commissioner of education in charge of vocational education, spoke on the working relationship of industry with vocational education. School Director Lowell Welsh, conducted the members on a tour through the departments of the school.

New Jersey

ANNUAL PICNIC

Union—The *New Jersey* Section held its annual picnic on Sept. 18th at the Old Cider Mill Grove in Union, with 840 members and friends in attendance. The brisk clear air of one of the season's most delightful days stimulated appetites and inspired many to participate in the variety of games and contest.

For those who preferred the more vigorous activities, there were games of softball, golf chipping, egg throwing, nail driving, fly casting and shot-put. Others pitched horseshoes, or played cards, . . . or just relaxed. Unlimited quantities of food including corn on the cob, hot dogs, hamburgers, barbecue, clam chowder, and, of course, lots of beer were available all afternoon.

The winners of contests and holders of lucky tickets took home dozens of prizes donated by 95 companies interested in the work of the SOCIETY. The money guessing game—highlight of the picnic—was won by Jim Von Rohr whose guess of $305.44 was off by only $1.32.

Hank Hoffmany and his committee deserve a great deal of credit for their fine job in making the picnic such a huge success.

HIGH-STRENGTH STEELS

Newark—Dr. Robert Stout, Lehigh University, spoke on "High Strength Steels for Welded Structures" at the *New Jersey* Section monthly meeting held on September 20th at the Essex House in Newark.

Dr. Stout described various methods of heat treating such steels as A285, A212, Jalloy 3, T-1, HY-80 and many others. He summarized evidence collected on the suitability of low-alloy steels for weldments designed to higher operating stresses. Most of the investigations have been sponsored by the Pressure Vessel Research Committee of the Welding Research Council.

The talk was supplemented with a very complete set of slides to better illustrate the test data he was reporting.

NUCLEAR FUEL ELEMENTS

Newark—Peter Patriarca of the Oak Ridge National Laboratory packed in a near record crowd at the *New Jersey* Section meeting on October 18th held at Essex House.

Almost 100 people at the meeting were present to hear the speaker give a light hearted explanation of the organization setup at Oak Ridge. His topic "Fabrication of Nuclear Reactor Fuel Elements" was very well presented and in easy to understand language. A color film showed the many detailed steps and precautions necessary in the fabrication of nuclear reactor fuel elements.

SUPPORT YOUR SOCIETY

LONG ISLAND GUEST

Guest Speaker C. B. Moore (right) of the Thomson Electric Welder Co. being greeted by J. Crowley (left) and Terry Imholtz of the Long Island Section

New York

RESISTANCE WELDING

Bellmore—The *Long Island* Section held its third meeting of the season on November 10th at the Sunrise Village in Bellmore. The guest speaker, Charles Dana Moore of the Thomson Electric Welder Co., Lynn, Mass., covered many of the resistance welding areas in his stimulating discussion.

The specific divisions of resistance welding were focused into the processes of spot welding, seam welding, projection welding and flash welding. They were discussed with operating principles and some applications as points of emphasis.

Two films on flash butt welding were shown. Of extreme interest was the film on flash butt welding of railroad rails. The entire operation of joining is handled on three flat cars with a progressive feed of individual rails being welded to produce a 1500 ft length.

This meeting, the third of its type, concluded an experiment in presenting the basic principles of the welding processes. The intention behind these discussions was to encourage consideration of welding process fundamentals and thereby refresh this knowledge and arouse interest in further search for information. It is hoped that this aim was accomplished.

ATOMIC FUEL ELEMENTS

New York—"Welding and Brazing in the Atomic Energy Field" was the subject of a talk by Herbert S. Kalish, chief of the nuclear metallurgy section, Metallurgical Laboratories, Olin Mathieson Chemical Corp., New Haven, Conn., at the October 11th meeting of the *New York* Section held at Victors Restaurant. The complexities of fuel element fabrication were discussed in detail. Each element must be indexed according to the suitability of alloys for nuclear work. Thus, the engineer is able to consult this ready reference source when considering new alloys for structural fuel elements.

Several combinations of materials are employed at present for both welding and brazing of aluminum and stainless elements. Atmosphere brazing as well as torch and flux techniques are utilized. Inert-gas tungsten-arc welding is mostly used in fusion applications and is considered the most efficient and versatile. Aluminum-silicon brazing alloys are employed for fabrication of complex units of aluminum. These alloys can be preplaced as cut rod or strip or the fuel element sheathing can be formed of 1100 clad on one or both sides with the brazing alloy.

Mr. Kalish projected several excellent slides showing various stages in the construction and fabrication of different types of fuel elements. The lecture terminated with a brief discourse on some of the more recent metals-joining processes such as the electron beam welding insofar as influence in the nuclear field is concerned. At this time, these new processes are gaining in significance and further exploration work is under way.

NATIONAL OFFICER'S NIGHT

Albany—The *Northern New York* Section held its first technical session of the season on National Officer's Night and were privileged to have National President R. D. Thomas, Jr., and National Secretary F. L. Plummer as dinner guests and speakers.

President Thomas presented an excellent discussion on electroslag welding, using numerous descriptive slides in which extremely thick sections were butt welded in a single pass with high deposition rates and without need for the usual weld joint preparation. In essence, this process differs from other types such as submerged or shielded metal-arc welding in that molten flux conducts the current and flux heat melts the filler wire and adjoining material to be welded. All welding is performed in the vertical up-position, with the joint thickness determining the number of parallel filler wires continually fed into the

NEW YORK SPEAKER

Herbert S. Kalish talking to New York Section on October 11th

NORTHERN NEW YORK GREETS GUESTS

AWS President R. D. Thomas, Jr. and National Secretary F. L. Plummer were speakers at the November meeting of the Northern New York Section. Standing, left to right, are: F. L. Plummer, Bill Owczarski, Lee Walker and C. H. Kreischer. Seated are: John Cuturillo, Professor Robert A. Wyant of Clarkson College of Technology and R. D. Thomas, Jr.

INFORMAL DISCUSSION AT CLEVELAND

Section officers discuss activities with national officers. Left to right in foreground are: National Secretary F. L. Plummer, Wasil Romance, Robert C. Pagenkopf, President R. D. Thomas, Jr. and Chuck Berka

A SPEAKER DINES

Frank Boucher (right) contemplates pleasant evening at Toledo Section where he was guest on October 19

flux bath at specific space intervals.

Considerable research and development work is being performed on electroslag welding originally developed in Russia with some contemplated variations in the European method of adding flux. Mr. Thomas pointed out as food for thought in this country that, if we are to compete with other markets in the field of heavy section weldments, we should consider this welding process, which is gaining popularity in many foreign countries.

An informative talk was presented by Secretary Plummer on the operation of the SOCIETY from a financial and technical viewpoint. Among other things, he pointed out that the distribution of technical publications by the SOCIETY is world-wide and provides a realistic income used for the continued publication of welding news and articles of interest to the membership.

NONDESTRUCTIVE TESTING

Olean—The *Olean-Bradford* Section held its monthly meeting on November 15th at the Castle Restaurant in Olean, N. Y.

Ross Shader of the Magnaflux Corp. presented an interesting talk, accompanied with slides on "Nondestructive Testing of Welds." The meeting was followed by a brief question-and-answer period.

North Carolina

SHOW AND SEMINARS

Raleigh—The *Carolina* Section was a co-sponsor of the second Southeastern Maintenance Show and Seminars held on September 14–16. Cooperating were local chapters of the American Institute of Plant Engineers and the N. C. Motor Carriers Association. Focal point of the welding exhibits at the show was the educational and membership display of the Carolina Section which featured original welded sculptures by member Roy Gussow.

Held in conjunction with the show was a series of seminars by each of the sponsoring organizations. The Welding Seminar featured several well-known speakers. The first day featured E. F. Iverson of Alloy Rods Co. who spoke on "Build-up and Hard Surfacing" and Helmut Thielsch of the Grinnell Co. who spoke on "Failures and Repairs of Piping Systems." The second day featured Van Rensselaer P. Saxe, consulting engineer of Baltimore, Md., who spoke on "Welding vs. Riveted Construction of Structural Steel" and J. P. Battema of Philips Electronic Instruments who spoke on "Nondestructive Testing of Welded Structures and Vessels." The final day featured J. W. Kehoe of Westinghouse Electric speaking on "Instrumentation for Resistance Welding" and Wm. F. Reuhl of Southern Oxygen Co. who spoke on "Inert-gas Welding." The question-and-answer period after each session led to some interesting discussions on welding and welding applications.

Ohio

WELDING MEDIUM WELDMENTS

Cleveland—The *Cleveland* Section directed the attention of their membership to manufacturing problems encountered when fabricating medium sized weldments. Attendance at the November 9th meeting, which was held at the Cleveland Engineering and Scientific Center, indicated the importance of this subject in the Cleveland area.

The meeting was highlighted by the presence of President R. D. Thomas, Jr., and Secretary F. L. Plummer. Both officers addressed the members prior to the panel discussion.

The panel members, Werner Gallo, chief welding engineer of Thew Shovel Co., and Robert Meyers, chief welding engineer of Harnischfeger Corp., were introduced by H. M. Bolander, meeting technical chairman and panel moderator. After the panel members reviewed actual experience with respect to fixturing and various fabricating problems, the meeting was opened to an informal question-and-answer period.

RESISTANCE WELDING

Columbus—On Friday, November 11th, a dinner meeting of the *Columbus* Section was held at the Florentine Restaurant.

The main speaker of the evening was Henry A. James, Research Engineer, Sciaky Bros., Inc., Chicago, Ill. His talk covered the fundamentals of resistance welding and how one can effect cost reductions by utilizing the new electrofusion method. He described the features of spot, seam, flash-butt, resistance-butt and projection welding. By using slides, he illustrated typical applications for these welding methods. In addition, Mr. James revealed resistance-welding techniques for producing assemblies which previously were arc-weldments or forgings.

The meeting was adjourned after a question-and-answer period.

HISTORY OF WELDING

Bucyrus—Harry Schwartzbart of Armour Research Foundation, was the main speaker at the *North Central Ohio* Section meeting held at the American Legion on November 3.

His presentation entitled "One Hundred Years of Welding" was accompanied with slides and was both very entertaining and enlightening as to the history of welding. He discussed the origin of welding and its development throughout the years, especially its development during World War I and later.

MULTIPLE-ARC WELDING

Toledo—The *Toledo* Section held its first technical meeting of the season on October 19th at the Toledo Yacht Club.

Seventy-eight members and guests enjoyed an informative discussion of automatic and semiautomatic welding, which was very ably presented by Frank Boucher of the Lincoln Electric Co.

The talk was accompanied by slides showing various applications of the submerged-arc and inner-shield processes. He also discussed multiple arc techniques which vastly increase travel speed and, in certain applications, can result in deposition rates approaching 200 lb. per hr.

Oklahoma

POWER SOURCES

Tulsa—A very comprehensive and thought provoking talk on "Power Sources for Arc Welding" was given by John H. Blankenbuehler, design engineer, Hobart Bros., Troy, Ohio, at the November 1st dinner meeting of the *Tulsa* Section held at Danner's Cafeteria. The presentation covered the fundamental requirements for arc-welding power sources. In addition to fundamentals, information was also presented on newer CV power sources. Slides were used to illustrate the talk.

INVESTMENT PLANNING

Part of group which listened to Harry K. Hiestand at Philadelphia Section meeting on October 13th

PHILADELPHIA PANEL

Panel members about to discuss "Operator Qualification" on November 4th. Left to right are: H. A. Sosnin, V. V. Meixell, C. Dooley and W. Scattergood

Oregon

ELECTRON BEAM WELDING

Portland—The *Portland* Section held a meeting on October 18th at the Henry Thiele Restaurant. Robert A. Stone of the Air Reduction Sales Co. Special Products Dept., spoke on the electron beam welding process. Mr. Stone gave a very good description of the possibilities for application of this system and required equipment. He used slides to show the three basic welding units; he also showed a film and described the latest production model.

WELDED GIRDERS

Portland—E. H. Weil, district manager of the Lincoln Electric Co., Portland, presented his paper on "Record Size Welded Girders" before the November 9th meeting of the *Portland* Section held at the Henry Thiele Restaurant. An excellent description of the fabrication of these girders in the shop and field using both manual and semiautomatic submerged-arc welding was given.

Pennsylvania

CARBON DIOXIDE WELDING

Allentown—The *Lehigh Valley* Section held their November meeting on the 7th at Walps Restaurant in Allentown, Pa.

The technical meeting speaker was Craig R. Sibley, section leader at the Development Dept. of the Air Reduction Co., Union, N. J. The speaker's subject was carbon-dioxide welding, and he stressed the importance of using this method to join mild steel. His most informative talk was illustrated with slides and high-speed motion films of the CO_2 welding arc.

In closing his talk, Mr. Sibley quoted a Russian engineer's experience with CO_2 welding of mild steel which explained why the Russians prefer this process over the covered-electrode process. This Russian engineer found that higher quality welds could be made with inexperienced operators using the CO_2 process instead of the covered-electrode process. In the question period which followed his talk, Mr. Sibley discussed a number of questions from the audience.

John Gosztonyi of the Gosztonyi Travel Agency in Bethlehem was the coffee speaker. His subject was "Travel."

ELECTRON BEAM WELDING

Philadelphia—David N. Reece, manager, Vacuum Furnaces Sales Dept., NRC Equipment Corp., explained in detail the recently developed electron beam welding process at the October 17th meeting of the *Philadelphia* Section.

With the help of excellent slides, Mr. Reece demonstrated precision welds being made at the bottom of a $^1/_{16}$-in. slot in a vacuum chamber, welds made between two surfaces at an acute angle, and welds having depth-width ratios of 4 to 1. Shown also were welds made on finish ma-

PITTSBURGH SPEAKER

E. H. Turnock just before he addressed Pittsburgh Section members on November 16

chined parts without distortion on materials normally considered problematic, such as tungsten, tantalum, columbium and zirconium.

Mr. Reece suggested that otherwise "unweldable" materials should be checked out for electronic beam welding. He further suggested that one's thinking should not be confined to the very thin sections, since thickness is not necessarily a limitation if the job must be done.

Prior to the technical meeting, Harry K. Hiestand of Reynolds & Co., stock brokerage firm, enlightened approximately 50 diners with an after-dinner talk entitled "Planning Your Investments."

OPERATOR QUALIFICATION

Philadelphia—On November 4th, Bill Brooks, panel chairman of the *Philadelphia* Section, presented his second panel meeting of the season. For a time, he felt that his whole world was collapsing when all three panel members, previously selected, became ill and were unable to attend. However, his popularity enabled him to call upon three other members at the last minute to make up an interesting panel, moderated by a very capable moderator in the presence of H. A. Sosnin, pipe engineer and designer.

The subject "Operator Qualification" provoked quite a bit of discussion. The panel members were Charles Dooley, Sun Shipbuilding and Dry Dock Co.; V. V. Meixell, Phoenix Steel Corp.; and W. Scattergood, Sun Oil Co. Although totally unaware of their assignment until the afternoon of the meeting, all panel members did an excellent job. Mr. Sosnin, as moderator, kept the discussion going at a good pace. Interest was still high when time ran out.

WELDING ALUMINUM

Shickshinny—The *Susquehanna Valley* Section met on November 2nd at Foot Hills Manor in Shickshinny for dinner and meeting. William Rogerson of the Aluminum Co. of America was guest speaker.

Mr. Rogerson restricted his topic "Welding of Aluminum" to the inert gas shielded-arc welding processes now in use in industry. He discussed the relatively rapid rise in ultimate tensile strengths in aluminum developed in the last few years. These relatively high tensile strengths have allowed aluminum to present a favorable strength-to-weight ratio in comparison to steel. As a result, the number of applications for use of aluminum are rapidly expanding. Some applications utilizing this strength-to-weight ratio are barge tanks, highway trailers for heavy equipment, bridge cranes, furniture and trailer truck tanks. The added advantage of the corrosion resistance of aluminum has doubled, tripled and quadrupled the life of oil storage tanks, oil pipelines, home fuel tanks for LP gas and tank-car tanks.

The talk by Mr. Rogerson was delivered and received in excellent fashion.

Rhode Island

WELDING EDUCATION

Providence—The *Providence* Section held their monthly dinner meeting at Johnson's Hummocks on Wednesday, October 19th.

Howard B. Cary, director of Hobart Brothers Technical School in Troy, Ohio, gave a talk entitled "Welding Education." Mr. Cary pointed out that the art of welding grew up through the shop and, because of this, had an extremely difficult time in gaining confidence of engineers and the trade. The welding industry now amounts to approximately one billion dollars and is still growing. The lack of trained welders throughout the country is so severe that, in some cases, designers and construction people have had to resort to the use of plastic piping and riveted bridges instead of iron pipes and welded bridges.

Mr. Cary indicated that, because of the lack of proper training, he has seen many misapplications for welding. At the present time the SOCIETY has an Educational Activities Committee, which is endeavoring to promote welding education. There are industrial art programs designed to familiarize students with the art of welding. The Government has created trade and industrial programs through the Smith-Hughes Act to formally educate people on the art of welding. The vocational agricultural program created by the Smith-Hughes Act also actively promotes welding.

Mr. Cary indicated that even with these programs, there was still not enough effort being applied to welding training. He recommended that the local sections impresses upon all local schools and colleges the need for welding training and demand that the schools sponsor this type of education. He stressed the need for all types of engineers to know welding, since just about any type of structure or unit that is built has the need for some type of welding.

METAL INERT GAS

Providence—Howard Miller of Linde Co. Development Laboratory

DEEP IN OIL COUNTRY

On October 13th, President R. D. Thomas, Jr. and National Secretary F. L. Plummer were entertained in true Texas fashion at Port Arthur. Present for the occasion and standing are J. B. Beard, H. A. Ritter, S. W. Scurlock, and President Thomas. Seated left to right are R. E. May, H. R. Snyder, J. A. Mayo, W. R. Dorrell, A. D. Sherer and H. R. Johnston

Twenty-four hours later both men were to experience an equally enjoyable time with the Tulsa Section. Seated left to right are: J. H. Tipton, F. L. Silvers, R. R. Vernon, R. D. Thomas, Jr., F. McSherry, H. R. Kretchmar. Standing are: L. Z. Johnson, J. H. Duerr, R. K. Hughes, R. H. Wainwright, D. G. Ellis, C. H. Huey and W. E. McWilliams

in Newark, N. J., presented an interesting talk entitled "Metal Inert Gas Welding," at the November 16th meeting of the *Providence* Section held at Johnson's Hummocks. Mr. Miller's talk was divided into two sections, one on the new developments in tungsten arc welding and the other on the gas-shielded-arc consumable-wire process. The development of the pilot-arc principle for tungsten arc welding, which provides for perfect and reliable starting of the arc, was described.

The Linde short arc process was described as a combination of a new type power supply, wire feed and torch equipment for using 0.030-in. diam. wire for many metals, and a new argon-CO_2 mixture for welding steel. This process has proved uniquely successful for welding sheet metal, for pipe welding and for filling unusual gaps caused by poor fit-up.

Tennessee

OXYGEN-ACETYLENE CUTTING

Kingsport—The *Holston Valley* Section held its regular dinner meeting October 18th at the Holiday Inn, Bristol, Va. The meeting was opened by Section Chairman Charles Griffin.

A brief business meeting was followed by the showing of a sound color film, entitled "Oxygen-Acetylene Cutting." The picture began with the early methods of gas cutting and progressed up to the present day and latest methods of gas cutting.

After the film, the chairman led a discussion on new methods of welding and also on some of the problems and experiences in welding encountered by the members.

PANEL FORUM

Nashville—A Panel Forum on "Specialized Welding Pertaining to Maintenance and Structural Welding" proved most interesting and showed the wide, varied and depth of "know-how" available among the members of the *Nashville* Section who met on November 10th at the Biltmore Restaurant.

The panel consisted of: Bill Regen, Moderator; Mike Below, Special Welding Applications; Russ Staub, Spot Welding, Resistance Welding and Related Applications; Miller Minton, Heavy Plate and Structural Welding; George Merrick, Shielded Arc Welding.

Texas

PIPE WELD FAILURES

Houston—The November Meet-

SOUTHERN HOSPITALITY AT ITS FINEST

The place is Washington, D. C., where President R. D. Thomas, Jr., and National Secretary F. L. Plummer found themselves in the best of company on September 15th. Left to right are: R. E. Lyons, M. F. Godfrey, C. H. Basel, M. L. Williams, F. L. Plummer, R. D. Thomas, Jr., C. A. Loomis, A. Piltch, W. E. McKenzie and R. H. Erest

October 6th was the date when President R. D. Thomas, Jr., and National Secretary F. L. Plummer enjoyed the hospitality of the Baton Rouge Section. Left to right are: E. Edley, J. Shilstone, R. D. Thomas, Jr. and J. York

The New Orleans Section was the scene of another enjoyable visit by President R. D. Thomas, Jr., and National Secretary F. L. Plummer on October 7th. Shown left to right are: C. Milford, President Thomas, L. Shirley and C. Cockrell

The October 8th Birmingham Section meeting was a memorable occasion for President R. D. Thomas, Jr., and National Secretary F. L. Plummer. Standing, left to right, are: R. A. Davis, W. W. McCain, R. D. Thomas, Jr., K. V. Nickell, C. T. Estock, W. R. McMahon and F. L. Plummer

ing of the *Houston* Section was held Nov. 16th at the Houston Engineering & Scientific Society with 125 members and guests in attendance. Among those present was Cliff Moss, district director.

The speaker of the evening, Helmut Thielsch, metallurgical engineer, of Grinnell Co., Inc., Providence, R. I., presented a down-to-earth discussion of the five basic causes of failures in pipe and pressure vessel materials: (1) improper engineering design, (2) incorrect selection and specification of materials (base metals and welding filler metals), (3) defects in the base metal or weld metal caused by faulty steelmaking practice, careless steel forming, shaping or heat treating and bad electrodes, (4) defective welding, and (5) failure due to service conditions more severe than originally assumed in the design and material selection.

Failures in weldments due to defective welding are by far the exception. Although the final customer or user is frequently inclined to blame weldment failures on the welder or welding fabricator, only in a few instances has this been substantiated. Since the majority of failures illustrated have occurred in code fabricated and inspected weldments, Mr. Thielsch also discussed the divergence between theory and practice in materials, fabrication and welding, and the fallacy of assuming that multiple inspection guarantees absence of hazardous defects.

Following the talk which lasted approximately 1 hr and 45 min., there was an interesting question-and-answer period.

COPPER AND ALLOYS

San Antonio—The *San Antonio* Section met on Nov. 7th at Captain Jim's with 45 members and guests attending.

Education Chairman W. H. Wood presented a series of slides entitled "Fire Prevention in Welding and Acetylene Cutting." The slides pointed out how easy it is to cause serious damage to property and personal injury by not using plain common sense.

Guest speaker, Joe Imperati of Anaconda American Brass Co. of Houston, spoke on the subject "Welding of Copper and Its Alloys." He presented a very interesting program of the nine types of AWS specifications of bronze rods and their use for production maintenance. A series of slides on various applications was shown with a lively question-and-answer period following the formal program.

Washington

EUROPEAN TOUR

Seattle—On Nov. 10th the *Puget Sound* Section was thrilled with an enthusiastic account of Professor Gilbert S. Schaller's recent tour of Europe. The good Professor gave an entertaining evaluation of industrial development, reconstruction and future competition patterns that may be expected. This technical travelogue was augmented by excellent colored slides. The subject was "Gibralter to Trondheim."

Wisconsin

EDUCATIONAL WELDING INSTITUTE

Madison—On Saturday, Oct. 22nd, the *Madison-Beloit* Section held its "First Annual Educational Welding Institute for High School Instructors." The meeting was held on the campus of the University of Wisconsin. Forty-four persons interested in welding were present. The morning program was devoted to speeches on various welding topics. Al Chouinard, vice president of the National AWS from the National Cylinder Gas Co. spoke on "How Important is Welding to American Ways of Living in 1960." Richard Ort from Handy Harman spoke on, "Silver Brazing and Braze Welding Should be Taught in the High School Industrial Arts and Agriculture Curricula." Don Helton from Harnisfeger Corp. spoke on "Arc Welding—Its Need and Application in the High School Curricula."

The afternoon was spent in the welding laboratories in the Mechanical Engineering Building. Throughout the afternoon on the half-hour a different demonstration and discussion of various welding processes took place. They were as follows: "Techniques in Gas Welding," M. Hippe, Linde Co.; "Techniques in Arc Welding," R. Stroesenreuther, Miller Electric Co.; "The Principle of Flame Cutting," Fred Gruhn, Red Arrow Sales; "Submerged Arc Welding," C. Heffernon, Linde Co.; "TIG Welding," Ed Shevey, Linde Co.; and "MIG Welding," W. Griskovich & B. Graves, Badger Welding Supplies. Following the demonstrations, a "Certificate of Attendance" was presented to each person present.

This type of program created a great deal of interest and enthusiasm among the high school teachers. A great deal of welding was sold in a short period of time. As a result of this successful program it is hoped that a three or four week summer instute in welding for high school teachers may be offered in the near future.

Should other AWS Sections be interested in promoting a similar program for high school teachers of welding, the Madison-Beloit Section would be happy to entertain inquires. Please contact the Educational Chairman Norman R. Braton, 1513 University Ave., University of Wisconsin, Madison, Wis.

POWER SOURCES

Milwaukee—The *Milwaukee* Section held its monthly meeting on Oct. 21st at the Ambassador Hotel. There were 82 members present.

The technical speaker for the evening was J. W. Pomazal, chief electrical engineer, Welding Div., Harnischefeger Corp., His topic was "Power Sources for Manual and Automatic Welding." He related by percentage the different types of power sources to be manufactured in 1961. He explained the advantages and disadvantages of the various types of welding machines and where they could be used to the best advantage. He also, by use of diagrams, showed how these machines functioned. Mr. Pomazal also discussed for the group the safe handling of welding machines and the danger of open circuit voltage under adverse conditions.

Plan Now to Attend
1961 AWS 42nd Annual Meeting
Hotel Commodore, New York City
April 17–21, 1961

New Members

EFFECTIVE NOVEMBER 1, 1960

MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

TOTAL NATIONAL MEMBERSHIP

Sustaining Members	199
Members	6,388
Associate Members	5,664
Students	300
Honorary Members	10
Life Members	30
Total	12,591

BATON ROUGE

Dicharry, Richard F. (C)
Hines, Earl H., Jr. (B)
Pixley, J. C. (C)

BIRMINGHAM

Griffin, Joe L., Jr. (C)
Mayr, Ward M. (C)
Reymann, Charles B. (B)

BOSTON

Caliri, Frank A. (C)
Harlow, Seaver R. (B)
Samoiloff, Alexander (B)

CANADA

Olins, Richard (C)
Slanina, Joseph (D)
Stuart, T. C. (B)

CHATTANOOGA

Jones, Wendell M. (C)

CHICAGO

Adelsperger, Fred (C)
Barton, Furman W. (C)
Berdnick, Nicholas (B)
Danielson, Worrell M. (C)
Ely, John B. (C)
Frey, Mel (C)
Griffith, Richard L. (C)
Hanlon, Richard L. (C)
Kane, Bob (C)
Lindstrand, Axel (C)
Pasko, John S. (C)
Quinlan, Amos L. (B)
Ruud, Clarence (C)
Tanner, George L., Jr. (C)

CINCINNATI

Schultz, Daniel M. (C)

CLEVELAND

Darbyshire, Jenine E. (C)
Goldsmith, Robert (C)
Meissner, Charles Edgar (C)
Ruppender, Robert R. (B)
Spahr, Gary L. (B)
Thomas, James W. (C)
Thorn, William S. (C)

COLORADO

Rice, Hubert J. (B)

COLUMBUS

Brutsche, Phillip A. (D)
Crawmer, Gerald R. (D)
Ingram, Carl R. (B)

DAYTON

Hickman, John Clinton (C)

DETROIT

Bracken, Garland C. (B)
Kinnamon, Charles E. (C)
Lane, Jack D. (B)
Russo, Charles V. (B)
Saari, Walfred M. (B)
Smith, Harold C. (C)
Van Landeghem, Gerard (B)

EASTERN ILLINOIS

Logan, Lloyd D. (B)

FOX VALLEY

Stoeger, Herbert F. (B)
Weekes, Eldon E. (C)

HARTFORD

Wodicka, John F. (B)

HOLSTON VALLEY

Lewis, Quentin H. (C)

HOUSTON

Billings, Benjamin R. (B)
Bohannon, Aubrey (B)
Brotemarkle, Lambert W. (C)
Lamb, Ray E. (B)
Leeper, William A. (B)
Lentz, Alex R. (C)
Peterson, George H. (C)
Sampson, Robert W. L. (C)
Smith, Harold E. (C)
White, Lewis H. (C)

INDIANA

Newman, Ralph (C)

J. A. K.

Burrows, Davis W. (B)

KANSAS CITY

Harper, Harry E. (B)

LEHIGH VALLEY

Kovalchick, Andrew S. (B)

LONG BEACH

Minnick, William H. (B)

LONG ISLAND

Kennedy, James R. (C)
Witt, Robert H. (C)
Zaremba, James (B)

LOS ANGELES

Grigg, Frank H. (C)
Masterson, John M. (C)
Pierce, Willis C. (C)
Sinnott, Charles M. (C)
Smith, William Robert (C)
Vidmar, Paul R. R. (C)
Vines, Clayton L. (C)

LOUISVILLE

Shaw, Robert W., Jr. (C)
Shirley, Glynn (C)

MADISON-BELOIT

Schroeder, H. W. (C)

MAHONING VALLEY

Brugler, Richard K. (C)
Fulton, Max E. (C)
Grisham, Clayton L. (C)
Nelson, William (C)

MARYLAND

Bandelin, Bernard G. (C)
Debusk, Joe W. (B)
Glaeser, Raymond A. (B)
Reihner, Jacob Franklin (C)
Walker, Harold S. (B)

MILWAUKEE

Bretschneider, Arno (B)
Kindl, Ralph J. (D)
Schultz, Roy A. (C)

MOBILE

Reed, Max Leroy (B)

NEW JERSEY

Balbi, Philip A. (C)
Campbell, John (C)
Cook, William P. (C)
Faucetta, Dominick (B)
Krzyanowski, Stanley L. (D)
Leighton, Thomas (B)
Morrison, A. V. (B)
Murphy, John R. (B)
Smith, Jack (B)
Tearpock, Daniel J. (C)

NEW ORLEANS

Engeran, Wayne J. (C)
Nelson, Waldemar S. (B)
Watts, Elbert Martin (B)

NEW YORK

Cassidy, Thomas F. (B)

NORTH CENTRAL OHIO

Dumbauld, Mark E. (C)

NORTH TEXAS

Stephens, Galen H. (B)

NORTHERN NEW YORK

Beach, Robert E. (C)
Higgins, John S. (B)
Huston, George L. (C)

NORTHWEST

Belleveau, Albert (B)
Hixson, Elmer (C)
Johnson, Richard E. (C)

NORTHWESTERN PA.

Huston, Alfred B. (C)

OLEAN BRADFORD

Bartman, Anthony (C)

ORANGE COUNTY

James, Bill (B)
Speer, George A. (B)

PEORIA

Hartzell, Paul D. (C)
Kennedy, Carl J. (B)
Muntz, Harry E. (C)

PHILADELPHIA

Gold, Stanley I. (D)
Maxwell, Herris M.. (B)
Sale, Frank A. (B)
Stopyra, N. J. (D)
Swiatkowski, Bernard (D)

PITTSBURGH

Hetherington, John F. (C)
Lord, Stanley B. (B)
Rueter, Frederick A. (C)
Snelling, J. Max (C)
Steppling, R. A. (B)
Webb, Ralph D. (B)
Worthington, J. C., Jr. (C)

PORTLAND

Marostica, George L. (B)

PROVIDENCE

Costantino, Joseph (B)
Damiano, Liugi (B)
Haley, Robert C. (B)
Stenberg, Oscar J., Jr. (B)
Tedeschi, Armand E., Jr. (B)

PUGET SOUND

Johnson, James O. (C)
Miraldi, Carl A. (B)
Steinkamp, W. I. (B)

RICHMOND

Battle, Joseph (B)
Penn, Raymond H. (C)

ROCHESTER

Mertz, Waite H. (B)

SAGINAW VALLEY

Payment, Michael (D)
Schneider, David R. (D)
Smith, Veral (D)
Tosch, John (D)

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DATE.....

NAME..... (LAST FIRST MIDDLE)

RESIDENCE ADDRESS

..... (STREET)

..... (CITY ZONE STATE)

COMPANY NAME.....

COMPANY ADDRESS..... (STREET)

..... (CITY ZONE STATE)

Title of position held.....

Mail should be sent to my residence ☐ company ☐ (check one)

I wish to be affiliated with the.....AWS Section

NOTE: To assure that your copy of the Welding Journal is mailed to your new address, this change of address notice must be received at American Welding Society, 33 West 39th Street, New York 18, N.Y., no later than the 25th of the month previous to issue mailing.

SALT LAKE CITY
Bailey, David R. (D)
Johnson, Howard (B)

SAN DIEGO
Hess, John D. (B)

SAN FRANCISCO
Holley, John A. (B)
Jones, Richard W. (C)
Kuhns, Robert E. (B)
Lair, John W. (C)

SANTA CLARA VALLEY
Cla ke, Van (C)

SHREVEPORT
Heller, M. M. (B)
Mitchell, Hilmon R. (B)

STARK CENTRAL
Cole, William I. (B)
Downs, Russell E. (B)
Schaffer, Peter H. (C)

SUSQUEHANNA VALLEY
Bower, Carl G. (C)

SYRACUSE
Smith, Richard F. (B)

TRI-CITIES
Reeves, Henry E. (B)

WESTERN MASSACHUSETTS
Kappler, Theodore W. (C)

WORCESTER
La Riviere, J. B. Roger (C)

YORK-CENTRAL PA.
Gulya, John A. (C)
Metz, H. R. (C)
Warnick, Arthur C., Jr. (B)
Zinkand, William C. (B)

MEMBERS NOT IN SECTIONS
Ramon, Jaime, Jr. (B)
Filippini, Ernesto (B)

Members Reclassified During November

ALBUQUERQUE
Thomas, John W. (C to B)

BOSTON
White, Sheldon Seymour (C to B)

J. A. K
Zegers, Vernon R. (C to B)

LOS ANGELES
Lehman, W Ford (C to B)

NEW YORK
Gibson, C. D. W. (C to F)

MEMBERS NOT IN SECTIONS
Suzuki, Haruyoshi (C to B)

NEWS of the industry

Citation to McKay

At a recent recognition dinner in Pittsburgh, Pa., the York Chamber of Commerce awarded the McKay Co., Pittsburgh, Pa., a citation for their expanding role in developing the York, Pa., economy. In accepting the citation, Frank Zehnder AWS manager of the McKay Co.'s expanding York plant stated: "McKay is actively searching for other

Frank Zehnder

products to add to our line that will be compatible from a marketing standpoint with our present chain and welding electrode products. This will be accomplished by either entering into new manufacturing areas on our own, or by purchasing an already established business."

Mr. Zehnder further stated that the McKay Co. is "now engaged in a very extensive program of modernization and expansion in York involving a total investment of over a million dollars in new buildings, additions and new equipment."

UCC Opens Atomic Energy Exhibit

The world's largest operating model of a nuclear research reactor and what is estimated to be the largest working model of a uranium atom was recently displayed at Union Carbide headquarters, 270 Park Ave., New York, N. Y. Both are part of a city block-long atomic

energy exhibit which is open to the public.

Guests at the opening included John A. McCone, chairman of the Atomic Energy Commission. While stressing the tremendous future of atomic energy for peacetime uses, he also described Armed Force tests which he had recently witnessed—one by a Polaris submarine, the other by only a few aircraft from one Strategic Air Command base. In each test, more fire power was available than unleashed by all warring nations during the entire course of World War II.

The exhibit opening also marked the completion of Union Carbide's move from its previous quarters at 30 E. 42nd St. in New York City. Features of the new site include 325,000 sq ft of glass, 30,000 tons of structural steel, 100,000 tons of concrete, some 70,000 separate lighting units for nearly 800,000 sq ft of ceiling and the installation of more than 20 miles of movable interior-wall partitions.

New Carton for Airco Electrodes

The Air Reduction Sales Co., 150 E. 42nd St., New York, 17. N. Y., has taken advantage of a new packaging idea which minimizes the absorption of moisture in low hydrogen type electrodes in introducing its new Barrier Carton.

The entirely new packaging insures freshness and dryness of the electrodes to be used in applications where close control of moisture content must be achieved. Moisture "resistance" is achieved in Barrier Cartons by an inner layer of aluminum foil in the courrugated cardboard.

Laboratory tests demonstrate the moisture absorption resistance superiority of this new packaging. When stored for a 19-day period in a chamber at 80 to 85° F and 85 to 90% humidity, it was found that low hydrogen type electrodes absorbed only 0.36% moisture as compared to 3.17% for those packed in regular styled cartons.

In using the new containers, Airco hopes to eliminate the very damaging problem of excess moisture the electrodes pick up in transit and storage.

COMING EVENTS

A Calendar of Welding Activity

ASM

Mar. 20–24, 1961. 12th Western Metal Congress and Exposition. Pan-Pacific Auditorium, Los Angeles, Calif.

AWS

Feb. 1–2. 7th Annual Midwest Welding Conference, Armour Research Foundation and Chicago Section. Illinois Institute of Technology, Chicago.

Mar. 24–25, 1961. Kansas Welding Show. Kansas National Guard Armory, Wichita.

April 17–21, 1961. 42nd Annual Meeting & Welding Show: Hotel Commodore, New York, N. Y.

NWSA

May 8–10, 1961. Seventeenth Annual Convention, Hotel Commodore, New York, N. Y.

Spot Weld Easier with Tuffaloy — For Less!

NEW IDEA!
ALL ALUMINUM SPOT WELDING TIP HOLDER

It took a complete departure from previous manufacturing methods to come up with this low-cost, high quality spot welding tip holder (each is a slice of a giant aluminum extrusion). These TUFFALOY holders are corrosion resistant, carry threaded tip adapters to take the brunt of tip socket wear. For welding pressures to 1000 lbs.

THE TRADEMARKS TO TRUST
AIRCO

NEW IDEA!
PADDLE-TYPE HOLDER
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A new design idea makes this TUFFALOY Holder more rugged, long-lived, and lower in cost to use—no tee connector is needed. Ideal for spot welding in restricted areas. TUFFALOY Socket-Type Tips (four nose types available) may be inserted on either side of the paddle.

Doc Tuffy says . . . be quick to use everything that improves your product or cuts your cost if you want to stay ahead of the pack . . . better get with TUFFALOY; we're coming up with the new ideas in our field.

Write or call your nearest AIRCO or TUFFALOY distributor for more information about these holders. Also request the new TUFFALOY Catalog; it describes the new RW Taper numbering system for spot welding electrodes.

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New Business from Pullman

Pullman-Standard, a division of Pullman Inc., has announced orders for 323 of its revolutionary 87-ft long Lo-Dek piggyback flat cars, a car designed to solve railroad overhead clearance problems in piggybacking, cut deadweight and to spur growth of rail traffic in new automobiles.

Of the 323 cars ordered from Pullman-Standard, 200 have been ordered by Trailer Train Co. and 123 by North American Car Co. Trailer Train will assign 140 cars to the Louisville & Nashville and 60 to the Chicago & North Western while 16 of the North American cars will be leased to the New York Central System for auto service and seven to the Western Maryland.

National Welding Competition for All Shop Students

All high school students will be eligible for the first time to compete in a national welding competition sponsored by The James F. Lincoln Arc Welding Foundation, it was announced today by Charles G. Herbruck, foundation secretary, in releasing details of the $15,000 award program for 1960–61. Formerly, only vocational agriculture students were eligible.

Cash awards totaling $7500 will be made this year in each division—agricultural education and industrial education.

The individual education division is split into two sections: one for students taking industrial arts; and one for students taking vocational trade and industry. Each section lists 61 awards totaling $3750.

There will be three first prizes, each worth $700. Each second prize will be $600; third prize, $300. There will be multiple fourth, fifth and sixth place awards of $150, $50 and $25 each.

Awards will be given to full-time day high school students who prepare and send to the Foundation the best descriptions of how arc welding was used on a school-supervised project for maintenance, repair or construction. Projects may be made either by individual students or by groups of two or three students.

Details of the 1960–61 competition may be obtained from The James F. Lincoln Arc Welding Foundation, Cleveland 17, Ohio.

SUPPORT YOUR SOCIETY

Lincoln Farm Student Awards

Led by Lowell Depping of Walla Walla, Wash., 107 farm boys from 22 states shared cash awards ranging from $25 to $600 each, in the annual national welding competition for vocational agriculture students sponsored by the James F. Lincoln Arc Welding Foundation, Cleveland, O. Depping won first award of $600 with an integrated forage feeding system capable of handling 60 head of dairy cattle. His "system" includes a portable self-feeder and a dump truck for filling the feeder. The project was built as a shop project at Walla Walla High School, which received a matching award of $600.

Second award of $400 went to Richard Rumph of West Plains, Mo., for a two-wheel utility trailer. Third awards of $200 each were won by Michael Brabec of Deaver, Wyo., for his power-driven hacksaw, and Richard Hogan of Kinsley, Kan., for his tractor-mounted scraper blade.

Leading state in number of winners was California, with 17. Top high school for the second year in a row was Tulare Union High of Tulare, Calif., with 11 winners.

Judges included Dr. E. E. Dreese of Ohio State University; Professor Irvin C. Cross, Colorado State University; F. N. Flowers, Kilbourne, La., High School; and Henry B. Pack, Appomattox, Va., High School. The Lincoln Foundation annually awards a total of $7000 to students and high schools for shop projects involving welding. Awards are made on the basis of usefulness and quality of the project and how well and completely it is described.

New Name for Steel Tube

The Welded Steel Tube Institute, Cleveland, O., an organization representing more than 20 leading manufacturers of welded steel tubing, has announced a change of its official name.

The organization, founded in 1930 as an advisory group for the industry, was formerly known as the Formed Steel Tube Institute. The change, first in the group's 30-year history, was announced by Jehu R. Derrickson, executive secretary-treasurer.

A nonprofit organization, the Institute was established to encourage research and development, foster efficient production, inform member firms of technical advances in the industry and to explore new markets and product applications.

New Hobart Distributors

Hobart Brothers Co., Troy, O., has appointed the following new distributors: Worland Oxygen Co., F. Elden Cook, P.O. Box 37 (404 N. Railroad Ave.), Worland, Wyo.; Biscayne Welding Supply Co., 4149 E. Tenth Court, Hialeah, Fla.; Pierce Sales & Service, Abe K. Pierce, owner and manager, Route No. 1, Guymon, Okla.; Acetylene Products Co., Earl V. Fulkerson, President, 1760 S. Harding St., Indianapolis 20, Ind.; Duncan Equipment Co., Gene Nelson, President, P.O. Box 1270 (202 E. Main St.), Duncan, Okla.; Medico Industries, Inc., Frank Silva, 11–13 Tompkins St. (P.O. Box 711), Pittston, Pa.

Linde Unveils New Ribbonrail Equipment

A completely new rail welding system, a major breakthrough in railroad engineering, has been unveiled at Fond du Lac, Wis., by Linde Co., Division of Union Carbide Corp. This new equipment reportedly speeds welding time and slashes manpower requirements by more than 40%. It also is said to produce a weld superior in quality

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TEMPERATURES

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quickly
3- to 10-sec response
inexpensively
models from $77.50

with an instrument
of toolbox sturdiness
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Weld Rod Division
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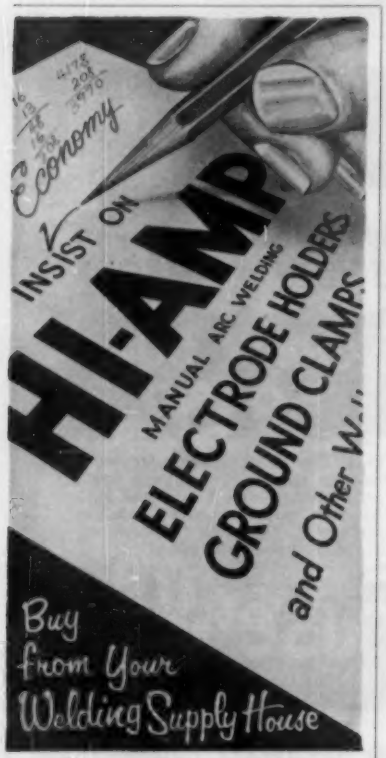
to those produced by any other equipment and it reduces equipment maintenance. Linde's Oxweld Railroad Department has been in the rail welding business since the early twenties and has been machine welding rail since 1938. The vast majority of welded rail in service today has been welded with Linde's "Ribbonrail" Service welding equipment.

Welded rail costs less to install and maintain than rail with bolted joints. Just how much a railroad saves by installing continuous welded rail varies with the individual railroad. However, a 1957 survey, conducted by the American Railway Engineering Association, stated that the average railroad saves $981 per track mile by installing continuous welded rail. Many industry officials say this savings figure is probably well over $1000 now, due to the inflationary wage-price spiral.

Regardless of what the amount saved by individual lines may be, the new equipment shown at Fond du Lac for the first time, may be able to save American railroads millions of dollars. Careful inspection was given the new equipment by more than 100 top engineering officers of key American railroads.



LENCO, INC.

BOX 192, JACKSON, MISSOURI

For details, circle No. 16 on Reader Information Card

FIFTH ANNUAL NEW ENGLAND REGIONAL CONFERENCE AND WELDING SHOW, OCTOBER 13–14

Vice-President C. E. Jackson opens conference and show by cutting chain. Looking on from left to right are J. Ritter, exhibition chairman; A. J. Rosenberg, general chairman; A. Bariloro, chairman Boston Section; F. J. Mooney, assistant secretary AWS; Colonel Wilkenson, Commonwealth Armory; and R. Grier, committee member

Scene at Exhibition which was attended by approximately 3200 visitors

Record Sales Posted by Air Reduction

Sales of the Air Reduction Co., Inc., for the nine-month period ending Sept. 30, 1960, were announced at a record $155,448,564, compared with sales of $151,052,893 for the first nine months of 1959, the previous record high. Net income for the first nine months of 1960 was $11,709,261, compared with $11,444,702 for the first nine months of 1959. Earnings per share of common stock during the first nine months of 1960 were $2.98, as compared with $2.94 for the first nine months of 1959.

Sales for the third quarter of 1960 were $50,504,023, compared with sales of $49,216,034, during the third quarter of 1959. Third quarter 1960 net income was $3,747,063, compared with third quarter 1959 net income of $3,627,580. Third quarter earnings in 1960 were $0.95, as compared with $0.93 for the third quarter of 1959.

The board of directors of the company declared the regular quarterly dividend of 62½¢ per share on the common stock of the company, payable on Dec. 5, 1960, to stockholders of record on Nov. 18, 1960. This will be the 174th consecutive regular quarterly dividend paid by the company on its common stock.

Shielded Appoints Distributors

As a result of Shielded Stud Welding Co.'s new policy of selling its stud welding equipment and studs through welding supply houses, the following firms have recently been appointed distributors under exclusive territorial franchises:

J. A. Cunningham Equipment, Phila., Pa.; Monson Welding Sales, Inc., Syracuse, N. Y.; The Welders Supply Co., Baltimore, Md.; Delta Oxygen Co., Inc., Memphis, Tenn.; R & R Welding Supply, Des Moines, Iowa; McDonald & Wilson Sales Co., St. Louis, Mo.; G. S. Parsons Co., San Diego, Calif.; Alex Latta Ltd., Edmonton, Alberta, Canada; Curtis Wells Ltd., Toronto, Ontario, Canada.

Hughes Appoints Sales Representative

Earl Chafin Associates has been appointed sales representative for thin metal welding machines manufactured by the vacuum tube products div. of Hughes Aircraft Co., Culver City, Calif., it was announced by Gerald E. Woods, division welding equipment sales manager.

Chafin Associates, 1541 Olympic Blvd., Los Angeles 15, Calif., will serve Southern California and Arizona and joins a nationwide group of welding specialists representing the Hughes line of stored energy and a-c line type resistance spot and seam welding machines, low inertia weld heads and handpieces and related accessories designed especially for difficult applications and metals.

Hobart Offers Workshop Courses

The Hobart Technical School, Troy, Ohio, has scheduled five courses in the first half of 1961 for welding supervisors, inspectors, plant managers, welding foremen and welding engineers. Each course will last 5 days. The three offered in January are:

1. Induction Heating for the Welding Industry—Jan. 9 to 13
2. Welding Fundamentals for Supervisors and Engineers—Jan. 16 to 20
3. Arc Welding Inspection and Quality Control—Jan. 23 to 27.

The two courses on welding fundamentals and inspection will be repeated in May. The registration fee for each 5-day course is $50. Reservations may be made by telephoning FEderal 2-1223 or by sending a wire or letter to School Director, Hobart Brothers Technical School, Troy, Ohio. The Short Course Bulletin, Winter-Spring 1961, with detailed information is available upon written request.

LINCOLN AWARD TO MITCHELL WELDING

Gove Mitchell, second from right and Jack Fenstermacher, center, accept Lincoln Electric Co. award on behalf of the Mitchell Welding Supply Co.; others are K. S. Roscoe, left.; E. E. Goehringer, second from left; and A. T. Bavaria, right.

Mitchell Welding Named Weldealer of Year

The Lincoln Electric Co., Cleveland, Ohio, has named Mitchell Welding Supply Co., Scranton, Pa., "Weldealer of the Year." The award presented to Gove Mitchell, president, and Jack Fenstermacher, general manager, cited the company for "outstanding achievements in performance, cooperation, development and leadership." It stated that their "...recognition of need for and application of unusual and exceptional programs combined with development activity to benefit and stimulate the acceptance and use of arc welding in your community has set a high standard of accomplishment and success."

In making the award, Mr. Roscoe, executive vice president and general sales manager of Lincoln Electric, cited Mitchell's unyielding efforts to increase sales volume in spite of a 75% decline in hard coal mining which had been the major Scranton industry. He lauded Mitchell Welding Supply for its participation in project "LIFE" a successful program to revitalize Scranton's economy as well as the dealer's adherence to Lincoln's proved sales policies.

Mitchell Welding Supply started business in 1928 in Kingston, Pa., moving to Scranton in 1930. In addition to their present location at 919 Jefferson St., a stocking warehouse and store is maintained in Wilkes-Barre.

APRIL IS NATIONAL WELDED PRODUCTS MONTH

VISIT THE A.W.S. WELDING SHOW

LOOKING FOR AN AD?

See the **Index to Advertisers** on page 106—the back of the Reader Information Card

PERSONNEL

Metal & Thermit Appoints Four

Four new appointments were recently announced by Metal & Thermit Corp.—Chester F. Delbridge AWS as product manager, welding equipment and accessories; Harold W. Mears AWS as northeastern states regional sales manager; Robert E. Casick AWS as welding sales engineer; and George W. Walberg AWS as welding machine specialist.

Mr. Delbridge was formerly president and general manager of Superior Industrial Gas Corp. Prior to this post, he served K-G Equipment, Inc., American Gas & Chemical Corp. and Air Reduction Sales in various executive capacities. Prior to his new assignment, Mr. Delbridge was northeastern states regional manager of M&T's Welding Division; he joined the company in 1954 as staff assistant in the New York office.

Mr. Mears, who will have his headquarters in Rahway, N. J., has been with M&T since 1955, serving recently as welding sales engineer. He was previously vice president of Standard Steel & Wire Co., in Bolivar, Pa.

Mr. Casick will be headquartered at the M&T in East Chicago, Ind., regional office and will provide technical assistance and service in Wisconsin and Northwestern Michigan; prior to his new appointment, he was with the Champion Rivet Co.

Before joining M&T, Mr. Walberg was a welding engineer at the Budd Co., in Philadelphia, Pa.

Saranac and Florestano Become Managers

Eutectic Welding Alloys Corp., Flushing, N. Y., has named George E. Saranac as advertising manager and Ernest J. Florestano AWS as district manager in the Maritime region of Virginia.

Prior to joining Eutectic, Saranac spent 11 years in agency account work handling industrial accounts in the fields of electronics, electrical control, metals production and aviation. He has been serving as assistant advertising manager and creative director since joining the company in 1959.

Florestano joined Eutectic as a technical representative in 1954 and in 1957 was awarded the Distinguished Salesman Award for the southern region by the Sales Executive Club.

Beckstrand Appointed

The appointment of R. Gail Beckstrand sales manager was announced by Birdsell Div., Susquehanna Sciences Inc., Pasadena, Calif. The firm, recently acquired by the Susquehanna Corp., Chicago, Ill., manufactures a complete line of welding machines.

Beckstrand was formerly sales manager of Anderson Equipment Co., Los Angeles, for 6 years and prior to that, a sales engineer 14 years with Linde Co., Division of Union Carbide and Carbon Corp.

He is a former chairman, comp-

R. F. Casick

C. M. Walberg

E. J. Florestano

C. F. Delbridge

H. W. Mears

R. G. Beckstrand

troller and member of the board of directors of the AMERICAN WELDING SOCIETY, Long Beach, Calif.

Bovie Advances

D. F. Bovie AWS has been appointed assistant manager, engineering services in the Pittsburgh district of Air Reduction Sales Co. Airco's eastern region. He will be responsible for the demonstration, installation and maintenance of the company's products in the Pittsburgh district.

Mr. Bovie joined Airco in April 1953. Initially, he worked for the company in the Cleveland district as an arc-welding salesman and engineering services representative. Mr. Bovie was transferred to the Pittsburgh district in October 1958 as supervisor of engineering services, serving in this capacity until his present promotion.

Mr. Bovie holds a bachelor of welding engineering degree from Ohio State University and is presently working for a bachelor of electrical engineering degree at the Carnegie Institute of Technology. As an associate member of the AMERICAN WELDING SOCIETY, he has served in local chapters as chairman of its education and television committees as well as vice chairman of its sessions committee of local chapters and representative to the council of professional societies.

McGonagle Named

John J. McGonagle has been named New York district manager in the warehouse division by Chase Brass & Copper Co., a subsidiary of Kennecott Copper Corp., Waterbury, Conn. McGonagle had been with Edgcomb Steel & Aluminum Corp. of Hillsdale, N. J., as sales manager and assistant to the president since 1951.

Hackett Marks 50th Year in Welding

Albert E. (Al) Hackett AWS, sales-engineering representative for Progressive Welder and Machine Co., Pontiac, Mich., was honored at a special recognition luncheon on October 17th, which marked the completion of his fiftieth year in the resistance welding field.

Al Hackett, widely known as the "grand old man of welding," literally grew up with the infant resistance welding industry and is an authority on welding practices and equipment. He was instrumental in the introduction of resistance welding in the fabrication of automobile bodies and the working out of handling systems which opened the way for today's all-welded bodies and automated production lines.

Progressive Welder President, Ray Heiden (left), presents gift to A. E. Hackett-on his 50th anniversary in resistance welding

Throughout his long career Mr. Hackett has been responsible for many important innovations and improvements in resistance welding, and is well known in automotive and metal fabrication fields.

Vice Presidency for Chisholm

Charles G. Chisholm has been appointed vice president—marketing of Haynes Stellite Co., division of Union Carbide Corp., it was announced by Robert M. Briney, division president. Mr. Chisholm had been general sales manager of the company since 1956. Before that he was sales development manager for six years. He joined Haynes Stellite in 1933 after graduation from Lafayette College where he received the degree of B.S. in chemical engineering.

Reinhardt Becomes Sales Manager

H. Brown Reinhardt has been named eastern sales manager for the American Manganese Steel Div. of American Brake Shoe Co., and will be based at the Amsco plant in New Castle, Del. He succeeds E. J. Nist, who has reached retirement age, but who will continue to represent Amsco in the Southeast.

Mr. Reinhardt attended Haverford School, Pa., and received his B.S. degree from Yale in 1930. After extensive industrial experience he joined Amsco in 1943 as a division engineer. He was named chief engineer in 1948 and excavator sales engineer in 1953.

GENERAL MANAGER

Full responsibility for sales production and engineering in small to medium sized manufacturing company engaged in welding and cutting equipment business. Prime assignment consists of continued development of sales area to increase share of market. Approximately 50% of time is spent in the field with direct sales force, distributors and other outlets in the industrial gas business concerned with welding equipment sales. Market analysis and competitive pricing important management factors. Success of individual and company's profits are related to sales growth. Present product line and contemplated addition will back up this effort. Close relationship with manufacturing and engineering through strong supervisors is available.

This position will provide a significant opportunity for the talented manager.

Submit complete resume in confidence including salary requirements

Box V-396, WELDING JOURNAL

Love Named Budd Marketing Manager

The naming of Richard E. Love as marketing manager of the Instruments Div., the Budd Co., Phoenixville, Pa., was announced recently by Dr. John H. Buck, vice president and division general manager. In his newly created position, Mr. Love will have complete responsibility for Instruments Div. sales, marketing and promotion of its many product lines in the fields of nondestructive testing, material testing, radiography and quality control.

Mr. Love comes from the Weston Instruments Div. of Daystrom, Inc., where he was industrial market manager at Newark, N. J.

Hanbery Appointed Manager

Don T. Hanbery has been appointed manager of the new Falk Corp. district office in Minneapolis, Minn., at 5009 Excelsior Blvd., it was announced recently by T. F. Scannell, vice president-general sales manager. H. R. Harris former Falk representative for over 30 years, will continue in a consulting capacity.

An engineering graduate of the University of Minnesota, Hanbery has been associated with The Falk Corp. since 1957. After completing his sales orientation course, he was assigned to the Detroit office as a sales engineer, a position he has held until his coming to Minneapolis in September.

Kadonoff Appointed

The Stoody Co., Whittier, Calif., recently appointed Max Kadonoff as field representative for the eastern part of Canada where he will work with Air Reduction Canada Ltd., on hard-facing problems in Ontario, Quebec and the Maritime provinces. Connected for many years with the welding and maintenance fields, Mr. Kadonoff formerly served as a welding specialist for Canadian Fairbanks-Morse, as manager of the eastern Canada area for Smith Welding Equipment Corp., and for ten years acted as maintenance supervisor with Cooksville La Prairie Brick & Tile Co. Ltd. During second world war he saw service with the Royal Canadian Electrical and Mechanical Engineers.

Green Chosen

The appointment of F. W. Green to the Resistance Welding Control Dept. was announced by the General Electric Co., Detroit, Mich. At Detroit, Mr. Green will be active in control engineering and development. His duties will include the engineering of GE products for resistance welding. He enters his new assignment work with more than 15 years of resistance welding machine design experience.

Tube Turns Names Nine

Establishment of a nine-region field organization was announced by John G. Seiler, president of Tube Turns Division, Chemetron Corp., Louisville, Ky., manufacturer of welding fittings and other piping components. Headquarters cities and newly promoted regional managers are: Atlantic region, New York— S. M. Hardison, formerly Philadelphia district manager; North Central region, Pittsburgh— Herbert P. Smith, formerly Pittsburgh district manager; Northern region, Chicago—J. C. Ellsworth, formerly Chicago district manager; Southeastern region, Atlanta— James F. Craig, Jr., formerly Atlanta district manager; Central Region, Louisville—E. R. Muir, Jr., formerly Louisville district manager; Mid western region, Kansas City—L.

EXPERIENCED WELDING SUPERVISORS

Required by

AN EXPANDING CANADIAN FIRM

A major steel fabricating company in Southern Ontario has two vital supervisory openints:

FITTING AND WELDING SUPERINTENDENT as head of the department of 50 skilled men and 4 foremen. Position requires high order technical ability, thorough knowledge of welding procedures and processes, outstanding organizing and supervisory skills, and a capacity for assuming responsibility in an independent manner.

FIELD WELDING SUPERVISOR to supervise the firm's present group of 14 welding supervisors in the field. Position requires a combination of extensive knowledge and experience in welding erection work, ingenuity in devising and implementing welding methods, and progressiveness in utilizing new ideas and methods.

Apply, in confidence, giving details of experience and salary requirements to:

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5. Have investigated new processes on basis of ads in Journal . . . 71%

K-508.1

LINCOLN WELDERS

three phase rectifier ***IDEALARC R3M®***

DC arc welders

Announcing a new family of ***LINCOLN WELDERS***

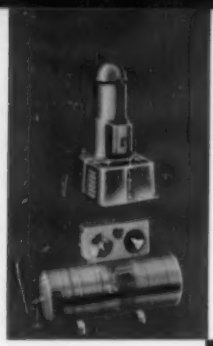
. . . full range of sizes, 300 amp to 650 amp

. . . generous capacity in each size

. . . ideal arc characteristics

. . . rugged, maintenance-free, construction

. . . surprisingly low price



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R3M-400
LINCOLN
WELDER

here are prices for the new

IDEALARC R3M

SIZE	PRICE*
300 amp	$610.00
400 amp	$660.00
500 amp	$735.00
650 amp	$1020.00

Lincoln gives more value for lower cost

*Delivered prices of standard machines in price Zone 1; slightly higher in 11 western states. Subject to change without notice.

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300 amp	$610.00
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500 amp	$735.00
650 amp	$1020.00

Lincoln gives more value for lower cost

*Delivered prices of standard machines in price Zone 1; slightly higher in 11 western states. Subject to change without notice.

A great new addition to the World's Most Popular Line of Welders

Lincoln's all new IDEALARC R3M

three phase rectifier DC arc welder

With such a large group of Lincoln welders already available to meet the needs of welding users, you might wonder why the new Idealarc R3M is necessary. Here is the reason—on some applications the following are either necessary or highly desirable:

1. DC welding current for small sized electrodes or stainless steel, alloy, non-ferrous or other special electrodes.
2. A current range broad enough to handle both semi-automatic equipment and small manual electrode.
3. A balanced, three phase input current.
4. Quiet operation.
5. Low idle currents.
6. High power factor and efficiency.

Only in a three phase rectifier, such as the new Idealarc R3M, can all these features be incorporated into one machine.

In addition to these features, the rugged construction of this new Lincoln welder promises to set new high standards of trouble-free operation and minimum maintenance. The highly efficient silicon rectifiers do not age or deteriorate and are exceptionally well protected against overloads with special electrical circuitry.

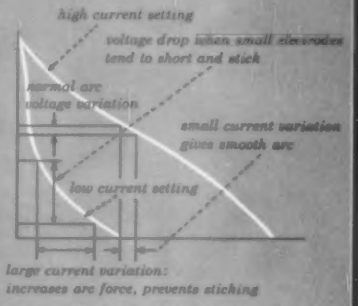
APPLICATIONS

For Manual Welding—The Idealarc R3M will handle *any* manual electrode. Its output characteristics produce smooth, steady, spatter-free welding at high currents and strong current surges that prevent sticking at low currents. In the production plant, maintenance shop, or the construction site, your operators will enjoy using the Idealarc R3M.

For Semi-Automatic Welding—The larger sized Idealarc R3M's, equipped with the optional "Power Pack", can be used as a power source for Lincoln's submerged arc Squirt Welders or other semi-automatic equipment. Equipped with two sets of leads, one Idealarc R3M can be used alternately for both manual and semi-automatic welding—double duty for added versatility and reduced capital investment!

PERFORMANCE FEATURES

Output Characteristics—Idealarc R3M has unique and important built-in characteristics that make welding easier. First, to prevent sticking with small electrodes, the machine produces a surge of current as arc length is shortened. This surge, seen as the "toe" of the low current settings curve, eliminates the need for separate switches and circuits to prevent sticking.


high current setting
voltage drop when small electrodes tend to short and stick
normal arc voltage variation
small current variation gives smooth arc
low current setting
large current variation: increases arc force, prevents sticking

Second, for smoothest operation of large electrodes, the output curve at high current settings is quite flat and relatively unaffected by arc length variations. There is minimum spatter and "wild arc" action.

Third, for maximum arc stability, R3M's choke coil is designed so that any electrode can be run at any appropriate current, using any technique, with complete freedom from pop-out.

Input Power—The Idealarc R3M draws a balanced three phase current from the lines. Particularly important where machines are installed on existing lines, this characteristic usually permits direct replacement of obsolete welders with new Idealarc R3M's without installation of additional wiring, switches or fuse boxes.

Starting and idle current on Idealarc R3M welders is practically nil, amounting to less than 15% of the rated input current. On field applications, the number of machines which can be powered by one generator set depends only on usable rated current, not starting current.

Power factor is high and idle amps low on the Idealarc R3M. Efficiency is excellent. Overall, for machines operating at rated load, efficiency is about 75%. Note that the silicon rectifiers contribute considerably to this. They are about 4 times as efficient as selenium rectifiers.

You'll find the Idealarc R3M welder truly ideal from the standpoint of every input power consideration.

Low Cost—After you've checked the performance and construction features of the Idealarc R3M and convinced yourself that it is tops in its class, then look at its price. You'll be pleasantly surprised.

LINCOLN IDEALARC R3M
Three Phase Rectifier, DC Arc Welder

CONSTRUCTION DETAILS

Current Control — An easily turned crank on the front of the machine provides continuous current control over the entire range of the machine by a movable core in the reactor windings. The mechanical system used to move the core is rugged, noise-free, smooth and free of creeping problems.

Polarity Switch — Durable, silver-plated contacts with sturdy mechanical construction assure thousands of trouble-free polarity changes.

Case — The recessed front prevents damage to external controls. Output studs are recessed even further and separated to eliminate accidental shorts. Strain relief loops prevent needless wear on output studs and loose connections that dissipate output and cause operator annoyances.

Lift Bail—Whether you move your machine once or hundreds of times, the convenience of the sturdy lift bail will be apparent. Welded directly to the sturdy frame of the machine, the lift bail is attached permanently regardless of how severely it is used.

Signal Light — Red light indicates machine is on; prevents accidental idle operation during non-working hours.

Line Contactor Starter and Overload Protection —Operated by a push button on the front panel, a heavy duty magnetic contactor energizes the machine. Protective circuits automatically disconnect the welder from the line in the event of overload, overheating from any cause, or input power failure. This well-proved protective system makes it virtually impossible to burn out the Idealarc R3M.

Weatherproofing — Louver design prevents entry of rain, or other falling liquids, into the machine. Also, electrical parts receive a double dip in a special insulating material after they are assembled and interconnected to repel the attack of salt air or other corrosive atmospheres.

Silicon Rectifiers — After years of testing, Lincoln engineers are convinced that the silicon diodes and circuitry employed in the Idealarc R3M provide unequalled rectifier performance and life. To the well-established efficiency and freedom from aging of silicon diodes, Lincoln has added exceptionally large safety margins and unique protective circuits to overcome the problem of overvoltage failures that plagued silicon rectifiers in the past. The results are outstanding.

Windings — Most of the windings in the Idealarc R3M are aluminum, which permit a compact, lightweight design. As in other Lincoln welders the aluminum-copper connections are flash-butt welded and sealed forever in a protective coating. There are no mechanical aluminum-copper joints.

Fan and Cooling System—A large fan moves generous quantities of cooling air through the machine. Clean air flows in at the top of the welder, passes first over the rectifier heat sinks, then down over the windings, and exhausts through louvers in the front panel. A large safety factor in temperature rise, designed in the machine, permits the use of the Idealarc R3M on even unusually severe applications.

SPECIFICATIONS

Idealarc R3M

Model / Type	60 cycle / 50 cycle	K-1149 / K-1153	K-1150 / K-1154	K-1151 / K-1155	K-1152
NEMA Rating:	Current	300 amps	400 amps	500 amps	650 amps
	Arc Voltage	40 volts	40 volts	40 volts	40 volts
	Duty Cycle	60%	60%	60%	60%
Current Range		30-375	40-500	50-625	65-750
Input Power:	Voltages*	208, 220/440, 220/550 volts			208 220/440
	Cycles	60 and 50			60
	Phase	Three Phase			Three Phase
	Rated Current (220 volts)	58 amps	75 amps	94 amps	120
	Idle Current	9 amps	11 amps	13 amps	13
	Power Factor @ Rated Load	74%	76%	75%	74%
Weights (Approx.):	Net	586 lb.	675 lb.	800 lb.	910 lb.
	Domestic Shipping	650 lb.	739 lb.	864 lb.	974 lb.
	Export Shipping	731 lb.	820 lb.	945 lb.	1055 lb.

Dimensions (all types)	Height	Width	Depth
Machine, overall	39¾"	26¼"	28½"
Export Crate	55"	36"	36"

*220/380 and other single voltages available on special order

OPTIONAL FEATURES

(at slight additional cost)

Undercarriage—provides portability. A sturdy three-wheeled undercarriage with either steel (K-726) or solid rubber tires (K-726R) is available for field installation.

Remote Current Control — Changes machine current setting from the operator's station with a simple toggle switch. The switch operates a motor inside the welder case which rotates control crank to adjust current up or down. Available factory-installed only.

ML-2 Power Pack—provides 115 volt DC control power and other circuits necessary for Lincoln ML-2 Squirt Welder. Available as a kit for field installation.

115 Volt Starter Circuit—for plants with regulations requiring 115 volts on starter push button circuits. Available factory-installed only.

Accessory Kit—includes headshield and lenses, electrode holder, ground clamp, and cables. Priced below total price of individual components.

Remote Polarity Control — Change from DC (+) to DC (—) or vice versa, with a switch attached to the electrode holder or mounted at the operator's station.

THE LINCOLN ELECTRIC COMPANY
Cleveland 17, Ohio

The World's Largest Manufacturer of Arc Welding Equipment and Electrodes.

LINCOLN USA

D. Hall, formerly assistant manager, Western sales; Mid-continent region, Tulsa—L. O. Morris, Jr., formerly Tulsa district manager (since 1955); Southwestern region, Houston—W. B. Whenthoff, formerly district manager in Houston; and Pacific region, Los Angeles—N. P. Boevsmer, formerly Los Angeles district manager.

Lyle Chosen District Manager

Stulz-Sickles Co., Elizabeth, N. J., producers of manganese and high carbon steel products for the repair and rebuilding of heavy equipment, has announced the appointment of W. C. Lyle, Jr., as district sales manager for the east-central section of the U. S.

Mr. Lyle, who resides in Bridgeville, Pa., was formerly associated with the Industrial Electrical Appliance Industry for 12 years covering the same area.

Brock Becomes President

Loring S. Brock was appointed president of United States Steel Products Div., New York, N. Y., effective November 1st. He succeeds John Hauerwaas who retired.

A native of Fort William, Ontario, he began his career with United States Steel in the shipping office of United States Steel Products at Los Angeles. He studied economics, metallurgy and marketing at the University of California, and later completed courses in sales analysis executive development at Stanford University.

After advancing through various assignments with the Products Div., Mr. Brock was appointed a salesman for the former Columbia Steel Co., in Los Angeles on July 1, 1930, rising to manager of manufacturing accounts solicitation by 1950. Following further advances, in March 1960 he was appointed executive vice president of United States Steel Products Div., the position he held prior to his present appointment.

Allis-Chalmers Selections

Six new appointments were recently announced by the Allis-Chalmers Mfg. Co., Milwaukee, Wis. These included the naming of J. H. Burrus and John M. Crawford as manager and assistant manager respectively of the new Allis-Chalmers thermal power department, and the selection of Joseph L. Desmond as works manager and Warren A. Kulberg as manager of industrial and community relations at the Boston Mass. Works. The final two appointments were the

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Design of load cell (only ⅝" between load points) is ideal for checking electrode force, as well as setup and maintenance of other mechanical or hydraulic equipment.

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naming of Robert N. Miers as consultant for the thermal power department, and Oscar A. Haas as manager of specialty products.

Mr. Burrus had been an assistant general manager of the Power Equipment Division since 1956. He came to the company in 1937 and was a representative in the Charlotte, N. C., and Portland, Ore., sales offices before being named manager at Portland in 1949. In 1950, he became manager of the Milwaukee district and four years later was promoted to manager of the midwest region with headquarters in St. Louis, Mo.

Recently receiving his M.S. degree in industrial management from Massachusetts Institute of Technology under an Alfred E. Sloan Fellowship, Mr. Crawford had been sales manager for large steam turbine generator units. He joined Allis-Chalmers in 1949 and was assigned to the steam turbine department in 1951 as an application engineer. He was named sales manager of large steam turbine generator units in 1957.

Mr. Desmond joined the Boston Works in 1942. He advanced to assistant foreman and foreman and in 1952 was appointed traffic manager. A year later he was named superintendent of production and in 1957 he became manager of industrial and community relations.

Mr. Kulberg has been with the Boston Works since 1936. In 1948 he was named foreman of fabricating shops and four years later, general foreman. In 1957 he was made assistant superintendent of production and in 1958 superintendent of production, the position held until his latest appointment.

Mr. Miers has been associated with Allis-Chalmers steam turbine department since 1928. He was successively resident turbine specialist serving east-coast offices and manager of the mechanical drive and industrial turbine section before becoming manager of the sales section in 1948.

Mr. Haas came to Allis-Chalmers in 1915 and was with the company's district sales organization for nearly 15 years before being named manager of the blower and condenser department in 1951.

Thomas McElrath, Jr.

OBITUARY

Thomas McElrath, Jr.

Thomas McElrath Jr., AWS, special project engineer for the Linde Co., Division of Union Carbide Corp., Electric Welding Development Department, Newark, N. J., died on Nov. 6, 1960, at the age of 41.

Mr. McElrath joined Linde in 1941 after graduation from Massachusetts Institute of Technology with degrees of Bachelor and Master of Science in Mechanical Engineering. He has been associated with inert-gas welding for many years and has presented five papers on various technical subjects at National AMERICAN WELDING SOCIETY meetings, with subsequent publication in the WELDING JOURNAL. (He has also given many lectures before local chapters of the AWS.)

After joining the New Jersey Section of the AWS in September 1950, he held the offices of Membership Committee Chairman 1953–57 and was elected treasurer for 1960–61. He has been on the Executive Council of the New Jersey Section since 1953.

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Shape: Sine pulse, 500 microsecond (at base)
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2,931,890—Electrode Feeding Device for Arc-Welding Apparatus—Arthur A. Bernard, Chicago Heights, Ill.

Bernard's improvement in arc-welding apparatus relates to apparatus wherein a welding torch is present and a length of electrode is fed to and through the torch to the arc by a pair of rollers engaging the electrode. Common switch means are provided in the apparatus to actuate the weld torch and to actuate a solenoid means that controls movement of one of the rollers toward the other for electrode engaging and feeding action whereby the electrode is fed toward the torch only when the torch is actuated.

2,931,967—Alternating-Current Welding Transformer — Henry Laurence Mills, Excelsior, Minn.

Mills' patent upon a welding transformer is directed to a construction wherein a secondary coil encircles a portion of a closed loop core of magnetically permeable metal. A main primary coil is positioned on a movable mechanical support, so as to encircle the core, that is movable with relation to the secondary coil. A supplemental primary coil is also present in the apparatus and is adapted to have power supplied thereto when the secondary coil voltage reaches substantially open circuit terminal voltage.

prepared by Vern L. Oldham

Printed copies of patents
may be obtained for 25¢ from the
Commissioner of Patents, Washington, D. C.

2,932,720—Metal-Welding Methods—Jacques Andre Stohr, Bures-sur-Yvette, France, assignor to Commissariat a l'Energie Atomique, State Administration, Paris, France.

In this welding method, two pieces of metal are placed in adjoining relation with respective edges thereof in contact with each other along a line and these metal pieces are held together under vacuum conditions and a focussed electron beam is directed onto the line, and the beam is accelerated along the path to the line. The beam is periodically interrupted while producing a relative controlled displacement of the interrupted beam and the whole of the two pieces to cause the beam to travel along the line of contact.

2,932,721—Metallic-Arc Welding with Stabilized Inert-Gas Shielding—Lambert F. Kooistra, Akron, Ohio, assignor to The Babcock & Wilcox Co., Jersey City, N. J., a corporation of New Jersey.

By the present method, an arc is maintained between a low carbon steel electrode with a carbon content of less than 0.35% and the work. Such arc is shielded with an inert monatomic gas in admixture with from 1 to 20% of a gas selected from the group consisting of carbon monoxide and carbon dioxide.

2,932,722—Electric-Arc Welding—Alexander Lesnewich, New Providence, and Everett H. Cushman, South Plainfield, N. J., assignors to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

A gas shielded metal-arc welding process is disclosed in which a direct current straight polarity arc is maintained between a consuming ferrous metal wire electrode and a workpiece. A flowing stream of carbon dioxide gas is used to protect the arc. A cesium compound is supplied to the arc end of the electrode and an adjuvant material is also provided which acts in the arc region with the cesium compound to cause the metal transferred across the arc to be transferred in the form of an axially projected spray of metal droplets.

2,932,723—Electric-Arc Welding—Craig Richard Sibley and Alexander Lesnewich, New Providence, N. J., assignors to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

The present patent relates to the same general process of welding as disclosed in Patent No. 2,932,722. In this instance, the steel electrode wire contains less than 0.25% of a deoxidizing material, and, in the spray transfer of molten metal from the electrode, a strongly deoxidizing metal is separately added to the weld pool to prevent the formation of pores in the solidified weld metal.

2,932,724—Arc-Welding Torch—Rodney G. Utter, Philadelphia, Pa., assignor to Superior Tube Co., Norristown, Pa., a corporation of Pennsylvania.

Utter's patent relates to a pencil torch for inert-gas arc-welding and it includes a metal tube and coupling means at one end of the tube for connection to a flexible cable supplying electrical current and inert gas. A rod-electrode holder is pivotally mounted on the opposite end of the tube for angular adjustment of the electrode relative to the path of gas discharged from such metal tube.

2,932,725—Electric-Arc Stud Welding—Arthur Ratcliffe Ainsworth, Tadworth, Donald John Taylor, Clapton, London, and Donald James Neville Laurie, Marlow, England, assignors to Crompton Parkinson Limited, Guiseley, England, a corporation of Great Britain.

A drawn arc-welding apparatus is covered by the present patent. The apparatus has mechanical means for placing two members into contact in the approximate position in which they are to be welded and also to guide the members in a relative separation and return movement. The patent relates to an improved electrical apparatus and circuitry to cause the relative separation and a controlled arc-weld action. Such improved circuitry and control means include a pilot arc circuit including the workpieces and having means therein limiting the current flow to a value below that required for arc welding. Other members are present to apply weld circuit conditions between the workpieces after a gap has been drawn between the workpieces and an arc established therebetween.

2,932,884—Method of Providing Bomb Head Shells with Drop-Ring Sockets—George Albert Lyon, Detroit, Mich.

Lyon's patent is on a method of forming a stud-like socket for a curved cylindrical wall such as that of a bomb or the like. In the process, an inwardly extending flange is provided in the wall and a combustible plug is inserted in the flange in snug engagement therewith. A flange cap is applied over the inner end of the plug and engaging the margins of the flange. The cap is then welded to the flange to form a socket opening outwardly of the wall but closed from the interior of the wall. The plug is destroyed by combustion during the welding action.

2,932,887—Method and Alloy for Bonding to Zirconium—Franklin D. McCuaig, La Grange, Ill., and Robert D. Misch, Whiting, Ind., assignors to the United States of America as represented by the United States Atomic Energy Commission.

This patent is on a method of bonding a member of the class of zirconium and zirconium alloys to a member of the class including zirconium, zirconium alloys, iron, steel, stainless steel, uranium, ceramics and cermets. The method comprises brazing the junction between the metals with an alloy consisting of about 6 to 9% nickel, 6 to 9% of either chromium, molybdenum or tungsten, and about zero to about 7.5% iron by weight with the balance of the brazing material being zirconium.

2,933,582—Induction-Welding Machine—Hubert L. Tower, Euclid, Ohio, assignor to American Roller Die Corp., a corporation of Ohio.

This induction-welding machine is for welding C-shaped skelp into tubing and it includes a roll forming stand on a frame that passes the C-shaped skelp to a welding station, and an insulated seam guide blade is carried on the frame subsequent to the roll stand and has a hollow insulator cooling chamber carried thereon in alignment with the axis of the skelp to be surrounded by the skelp. A magnetic core is positioned within the cooling chamber and an induction coil is present at the welding station subsequent to the seam guide blade. The position of the magnetic core is longitudinally adjustable within the coil to establish a concentrated flux along the axis of the skelp to heat the edges thereof.

2,933,587—Welding Throat for High-Frequency Alternating-Current Resistance Welding of Tubes—Ernst W. Allardt, Alliance, Ohio, assignor to The Babcock & Wilcox Co., New York, N. Y., a corporation of New Jersey.

This new resistance tube welding apparatus includes electric current conducting means engaging the converging edges of partly formed tubing upstream of the point of convergence of the edges for heating the edges by current flow therealong between the current conducting means and the point of convergence. A pair of laterally aligned squeeze rolls engage opposite sides of the tubing at the point of convergence with each roll engaging the tubing over an arc extending from a point diametrically opposite the converging edges to a point spaced from the converging edges, and a pair of coaxial pressure rolls electrically isolated from each other engage the tubing on either side of the converging edges over substantially all of the remaining arcuate extent of the tubing except for a small arc directly at the weld zone so that a weld throat is formed to enclose the tubing except for small clearances at the peripheries of the adjacent rolls and for the small arc at the weld zone.

2,933,588—Metals-Joining Apparatus—John L. Harper, Lackawanna, Pa., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

Harper's apparatus is on automatic means for producing cable sections with solidified ends by brazing a brazing ribbon to predetermined spaced portions of a cable. The apparatus includes means to advance the cable, sever it at the brazed area thereof, etc.

2,933,589—Electrical Resistors—Graham Pearce, Crick, near Rugby, England, assignor to Painton and Co. Ltd., Northampton, England, a British colony.

This patent to Pearce is on a method of welding an electrical lead to a metallic end cap for an insulating core carrying an electric resistive element. First an exterior recess is formed in the end of the cap and a core is fitted into the cap until it abuts against the inner surface of the recess. A protruding head is provided on an electrical lead to engage the recess and the lead is forced into the recess while current conducting electrodes are connected to the outer surface of the cap spaced from the recess and to the lead to electrically weld the lead to the cap.

New Literature

Flame Hardening Equipment

A 12-page brochure (ADC-704A) has just been released by Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y., on flame hardening equipment. Clearly illustrated and diagramed, the brochure discusses the various problems of oxyacetylene flame hardening and shows how these problems can be solved with Airco equipment.

All available equipment for the process is discussed—from standard heating torches and tips and water-cooled flame hardening torches to gear hardening equipment adapted to use with the No. 20 Radiagraph, a portable machine carriage that operates on a tongued and grooved steel track. The machine is said to be ideally suited for flat surface and gear hardening operations.

For your free copy, circle No. 51 on Reader Information Card.

Positioning Equipment Guide

The Ransome Co., Scotch Plains, N. J., has published a 16-page "Guide to Positioning Equipment." The Guide includes a reprint of an article by John Mikulak, which originally appeared in the *ASME Journal*. Mr. Mikulak discusses the basic reasons for using positioning equipment; describes the various kinds of equipment available (turning rolls, positioners, manipulators, etc.) and the kind of work each is capable of performing; and explains how various items of equipment are rated (size, capacity, power, etc.)

For your free copy, circle No. 52 on Reader Information Card.

Induction Heating Catalog

A 52-page catalog-handbook which pictures latest developments in Ther-monic induction heating equipment has been issued by Induction Heating Corp., 181 Wythe Ave., Brooklyn 11, N. Y.

The handbook gives illustrations and describes operations of a wide range of equipment which performs the tasks of hardening, brazing, forging, soldering annealing, shrink fitting and crystal growing by the most up-to-date methods. The catalog also describes a line of work handling equipment that can be tailored to fit each industry's individual work-holding problems. One section is devoted to new and improved electronic induction heating generators which feature a bench-type design, low cost and versatility.

For your free copy, circle No. 53 on Reader Information Card.

Training Film

A 16-mm film in full color and sound on shielded arc-welding procedures titled, "Fundamentals of Manual Shielded Arc-Welding Techniques," has been issued by Air Reduction Sales Co.

Adapted from General Electric Co.'s previously released six-film series, "Inside Arc-Welding," the Airco film has been edited to two reels and is 45 min in length.

Part One covers flat and horizontal arc-welding techniques and is 22-min in duration. The 23-min second reel studies vertical and overhead arc-welding procedures. Extremely clear camera close-ups of the welding arc in actual operation are featured in the film.

Since operator training is the primary purpose of the film, the four basic principles of arc-welding—current setting, speed of travel, length of arc and angle of electrode—are graphically explained. In addition, good and bad examples of arc welding are examined.

Film prints may be obtained on loan and without charge by contacting the local representative of Air Reduction Sales Co. listed in the telephone directory.

Stainless Steel Welding

A 2-color edition of the manual *The Welding of Stainless Steels*, designed to function as a general reference guide on the entire subject of stainless steel welding, has been published by the McKay Co., 1005 Liberty Ave., Pittsburgh 22, Pa.

Detailed explanations are given on the various stainless steels in common use today. The practical procedures for their welding and

types of electrodes and wires available for their use are covered in easy-to-follow question and answer form. Questions are aimed directly at fundamental welding problems—and the answers point out the reasons for these problems and methods for arriving at solutions.

In addition, the manual contains information on the specific effects of alloying elements in stainless steels and high strength heat resisting alloys. Also listed in a handy reference chart format, are the ASTM stainless steels with recommended electrodes in the welding of these steels.

For your free copy, circle No. 54 on Reader Information Card.

Data on Gases

Three 14-page illustrated booklets are available giving such essential information on gases as manufacturing, distribution, storage, safe handling, applications and engineering data. Booklet 5881 covers oxygen, 5896 covers nitrogen and 5897 covers argon. Any may be obtained by indicating number from Liquid Carbonic Division of General Dynamics Corp., 135 S. La Salle St., Chicago 3, Ill.

For your free copy, circle No. 55 on Reader Information Card.

C.B.&I. Survey

Craftsmanship in Steel is the title of a new brochure describing the products and world-wide coordinated services of Chicago Bridge & Iron Co., 332 S. Michigan Ave., Chicago 4, Ill.

The illustrated publication tells of company's capabilities in design, fabrication and construction of structures to serve leaders in the fields of nuclear power, aerospace, chemistry, petroleum, cryogenics, hydroelectric power, pulp and paper and saline water conversion.

For your free copy, circle No. 56 on Reader Information Card.

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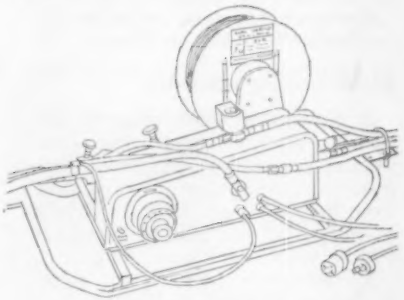
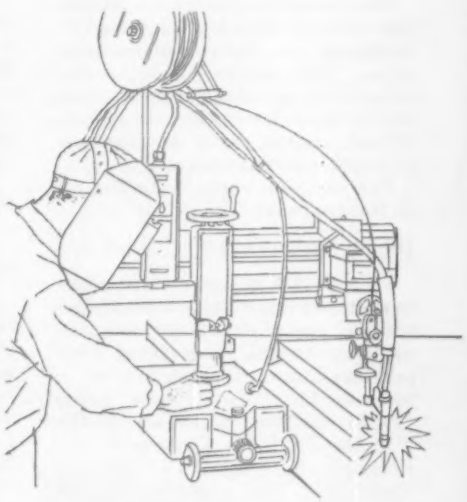
Progress means greater profits for you. The NCG AM-7 Gun for Automanual* welding is the newest, most improved consumable welding gun on the market. Its outstanding versatility, its low maintenance, its adjustable handle for welding ease and accessibility all mean increased production. And, it provides complete gas shielding using 25% less gas.

The multi-use barrel of the AM-7 Gun, designed for all MIG and carbon dioxide shielded welding processes, is interchangeable with the NCG A-10 Automatic Torch and may be used for all MIG, carbon dioxide shielded and TIG welding processes. And, for even greater versatility, a simple change of the guide tube accommodates ferrous or non-ferrous metals.

Send for complete information today. Ask for the new NCG Bulletin NH-142-E-1A, NATIONAL CYLINDER GAS DIVISION OF CHEMETRON CORPORATION, 840 North Michigan Ave., Chicago 11, Illinois.



The new WC series welding control units have features that were developed to meet field requirements. Designed for consumable electrode welding processes using argon, helium or carbon dioxide shielding gases, they provide maximum versatility and economy.



Multi-purpose barrel is interchangeable with the NCG A-10 Automatic Torch for MIG and TIG welding.

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Division of CHEMETRON *Corporation*

*NCG trademark for semi-automatic welding process and equipment

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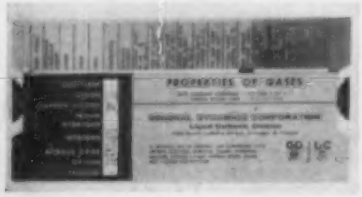
For details, circle No. 24 on Reader Information Card

Properties of Gases

A slide-indicator (No. 5860) that has settings showing 38 useful properties of nine industrial gases is



offered by Liquid Carbonic Division, General Dynamics Corp., 135 S. La Salle St., Chicago 3, Ill.

For your free copy, circle No. 57 on Reader Information Card.

Bench Welding Machines

A bulletin, in color, covering the Federal line of bench type spot welding machines illustrates and describes their line in capacities from 5 to 50 kva. Bulletin BA-60 is offered by the Federal Machine and Welder Co., Warren, Ohio.

For your free copy, circle No. 58 on Reader Information Card.

Aluminum Dip-brazing

John Gombos Co., Inc., Webro Rd., Clifton, N. J., announces the availability of their aluminum dip-brazing facilities brochure to industry.

Aluminum dip-brazing is a process that allows excellent joining of aluminum to form homogeneous parts. The process permits the creation of complex configurations, which were formerly impractical, difficult or too costly to fabricate by other known methods.

For your free copy, circle No. 59 on Reader Information Card.

Tubing Design Data

Information of interest and value to engineers and designers associated with the use of tubing for corrosion resistant service, or elevated temperature and/or pressure service, is included in a new data folder (T-456) recently published by the Tubular Products division of the Babcock & Wilcox Co., Beaver Falls, Pa. The folder shows the chemical analyses of the standard carbon, alloy and stainless tubing steels used in such service. It is cross-indexed to associate grade and ASTM Specifications with B&W's Nicloy, Croloy and specialty tubing steels. For ready reference, the bulletin also lists the ASTM tubing and pipe specifications by number and title.

For your free copy, circle No. 60 on Reader Information Card.

Eye and Face Protection

A selection of eye and face protection for a wide variety of industrial applications is described in a brochure (No. 0300-1) available from Mine Safety Appliances Co., 201 N. Braddock Ave., Pittsburgh 8, Pa.

Highlighted in the 40-page catalog is the Sightgard line of eyewear which reportedly combines maximum protection with the distinctive appearance of modern functional spectacles. This eye protection is said to provide high optical quality and impact strength in excess of specifications, and to meet individual needs and preferences through a variety of frames, temple styles, bridges and lenses.

Also reviewed in the catalog are vision testing equipment, goggles, faceshields, welding helmets and accessories and parts.

For your free copy, circle No. 61 on Reader Information Card.

Rubber Stamp Welding Symbols

A catalog offered by Paper Equipment Distributing Co., Technical Rubber Stamp Div., P. O. Box 90, Prince Street Station, New York 12, N. Y., covers sets of rubber stamps giving the standard symbols used in over 18 technical fields, including welding.

Designed to replace the more laborious drafting of numerous symbols on drawings or tracings, the rubber stamps come in sets of three basic designs offering flexibility through combination. A special ink is recommended for good results.

For your free copy, circle No. 62 on Reader Information Card.

High-temperature Alloys

A quick and ready reference to the comparative properties of their complete line of high-temperature alloys is now under one cover in a 20-page booklet newly released by Haynes Stellite Co., Division of Union Carbide Corp., 270 Park Ave., New York 17, N. Y.

For your free copy, circle No. 63 on Reader Information Card.

Safety Catalog

A total of 57 eye and face protection products and accessories is featured in a 16-page illustrated catalog (No. S-37) published by Sellstrom Manufacturing Co., Palatine, Ill. Included is a wide variety of plastic frame safety glasses, metal frame glasses, cover goggles and clip-ons, plant visitor glasses, fiber glass face shields, sweat bands, information on lenses and replacement parts.

For your free copy, circle No. 64 on Reader Information Card.

Foreign Books.—Reviews obtained from foreign periodicals by Gerard E. Claussen, contributor of "World-Wide Welding News."

Welding in Power Generation (Die Schweisstechnik in der Energieversorgung). Published by Deutscher Verlag für Schweisstechnik Gmbh, Dusseldorf 1960, 119 pages.

This is volume 17 of the West German Welding Society's series of books. It contains 19 papers delivered at the Berlin Welding Conference, June 1959. There are two papers on welding zirconium and uranium, five on welded piping and penstock and four on welded generators, and steam, gas and water turbines. Three papers describe the welding of copper and aluminum bus bars.

"Porogas" protective cylinders are used instead of chambers for welding zirconium. The cylinder is about 1 in. internal diam and is lined with a porous ceramic. Argon diffuses into the welding area in laminar flow through the porous ring.

The longest paper surveys steels, joints, and welding metallurgy of ferritic and austenitic steels for high temperature steam piping. An inconel electrode was used to weld a ferritic steel pipe (0.20 C, 11 Cr, 1 Mo, 0.3 V, 0.5 W) to an austenitic pipe (16 Cr, 14 Ni, 1.5 Mo, 0.70 V, 1 Cb). It was necessary to anneal the joint to soften the hard zone in the ferritic steel.

The paper on gas turbines describes the construction of rotors from three or more disks welded together. The rotor sections are assembled in the vertical position, the root passes being deposited by three tungsten arcs spaced 120 deg apart.

New Products

Diesel-driven Welding Units

Two new "Sureweld" diesel-engine-driven d-c arc welding power plants, designed to withstand rough usage in the field, are announced by National Cylinder Gas Division of Chemetron Corp., 840 N. Michigan Ave., Chicago, Ill.

The SDD-250 model has two welding ranges, a high of 150 to 350 amp, and a low of 50 to 200 amp. The unit has a rated output of 250 amp dc at 40 v, and provides 115-v d-c auxiliary power to operate portable hand tools while welding. The SDD-250-L model is identical except that it also offers 12 kw of 115/230-v, 60-cycle a-c power for auxiliary needs, and up to 6.5 kw a-c power while welding.

Both models are equipped with rheostats which provide stepless current control, optional remote controls and electric starters.

For details, circle No. 101 on Reader Information Card.

Micro-wire Welding Package

A constant voltage motor generator welding unit, rated 200 amp at 25 v and designed especially for automatic welding, has made it possible for Hobart Brothers Co., Troy, Ohio, to offer their Micro-wire welding process in a compact portable package.

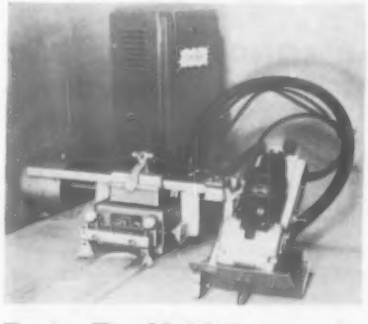
Micro-wire welding is a semiautomatic or fully automatic low amperage electric-arc process which continuously feeds a small diameter bare wire electrode into a welding zone shielded by a gas, usually carbon dioxide (CO_2) or a mixture of argon and CO_2. This open-arc process is said to produce a high-quality weld on various metals, particularly those in the sheet metal classification and where poor joint fit-ups are encountered.

The Model 1259 complete portable package unit includes a 200-amp constant voltage welder with ammeter and voltmeter, wire feed unit, Micro gun and cable assembly, gas regulator and flowmeter with hose and argon adapter fitting, all on a portable mounting with space for carrying two cylinders of gas.

For details, circle No. 102 on Reader Information Card.

Automatic Air-carbon Arc Unit

The Arcair Co., P. O. Box 431, Lancaster, Ohio, announces the development of its new Model Q-5 heavy - duty, automatic Arcair



Torch. The Model Q-5 was designed to automatically groove seams and prepare the edges of heavy plate for welding. It will enable production of "U" groove plate preparation by butting square edged plates together and producing the desirable "U" groove in two plates in one operation. Its fast travel speed and low heat input keeps plate distortion to a minimum.

The complete unit consists of a tractor-driven automatic head featuring all position adjustment of electrode angle and variable electrode feed. Included also is an Arcair Contractor with remote control switch. This provides maximum safety for operator and equipment by providing means of quickly cutting off power from the arc.

For details, circle No. 103 on Reader Information Card.

High-frequency Stabilizer

A high-frequency automatic arc starter and stabilizer, for use with any a-c or d-c welding machine, has been announced by Metal & Thermit Corp., Rahway, N. J. It is designed to eliminate false starts even with low open-circuit voltage, and to stabilize the arc on low-current settings for thin gage a-c

or d-c welding. Stabilization simplifies work preparation, with better penetration of dirt, rust, paint or oil films.

The new stabilizer, Model HF 60, operates from a 230-v, a-c source. Other primary voltages are available. The unit is rated at 600 amp capacity. Model HF 60R is equipped with remote control.

For details, circle No. 104 on Reader Information Card.

Spot-welding Tip Holder

An all-aluminum offset spot-welding tip holder is now available from Air Reduction Sales Co., a Division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y. The low cost of these new holders was made possible by use

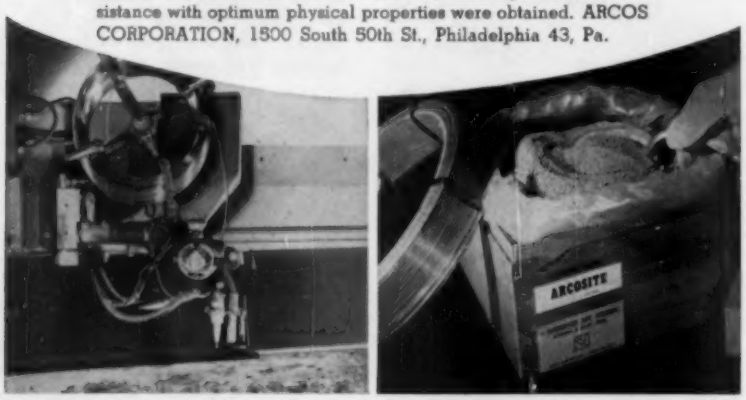
Job Report Courtesy of
Alco Products, Inc., Schenectady, N. Y.

Nuclear pressure vessel stainless clad at low cost

USE ARCOS

STAINLESS WIRE and BONDED FLUX

This "barrel" is one of several that comprise a nuclear pressurizer to operate under highly corrosive conditions. To reduce costs, Alco Products forged the shell of ASME A-336, 2—4 inch thick manganese molybdenum steel and clad the inside with stainless. The illustration shows the second pass overlay which was made by submerged arc using Arcos Chromenar K-LC (Type 308) bare wire and Arcosite S4 flux. Lower cost, and high corrosion resistance with optimum physical properties were obtained. ARCOS CORPORATION, 1500 South 50th St., Philadelphia 43, Pa.



Bare Wire

Arcosite Flux

For details, circle No. 25 on Reader Information Card

of a new extrusion method of manufacture. Tip adapters carry the brunt of holder wear, at the tip socket, and are easily replaced. Also, when alternating between 4 RW and 5 RW taper electrodes, only the adapter and adjustable water tube need be changed, not the entire holder. Holders come in standard 2- and 4-in. offset, and with shank diameters of $^{3}/_{4}$, $^{7}/_{8}$, 1, $1^{1}/_{4}$ and $1^{1}/_{2}$ in.

For details, circle No. 105 on Reader Information Card.

Unit Has 3-phase Input

The welding industry's first ac-dc arc welding machine with 3-phase input has been introduced by Vickers Inc., Electric Products Division, 1815 Locust St., St. Louis 3, Mo.

In the Vickers Controlarc, circuits utilize three-phase power to reportedly provide both the a-c and d-c outputs, with a range of 6 to 400 amp dc, 6 to 250 amp ac in the Controlarc Model 330. Full single range operation on ac and dc permits the use of standard Vickers slope controller without limitation due to range switches.

The machine also includes special low-range ac for high-performance low-current gas tungsten-arc and stick-electrode welding, with a low current resistor available for test lab and experimental welding.

Dual continuous control is maintained on both ac and dc, with adjustable controlled arc characteristics (curve slope and response speed). All models of the new Controlarc include as standard equipment selective arc starting circuitry with on-off switch, operating on both ac and dc; built-in gas and water controls; high-frequency arc starter located external to welder to permit placement in proximity to work; and standard Vickers foot control units and dual remote hand control units to adjust both a-c and d-c output currents.

For details, circle No. 106 on Reader Information Card.

Furnace-fused Overlay

Use of a unique sprayed-on furnace-fused stainless type surface overlay provides corrosion resistance equal to solid 400 grade stainless steel in a mild steel drive shaft for an outboard motor. The new technique has permitted an over-all reduction of more than 52% in production costs for the shaft.

Originally, the part was fabricated of 400 grade stainless steel and was produced by machining from the solid. The stainless material was selected for its corrosion resistance since the shaft projects into the water during normal operation.

In an effort to reduce costs, attempts were made at butt welding carbon steel to a stainless steel stub shaft section. Critical torsional strength requirements, however, made it impossible to produce a satisfactory drive shaft by this method.

The new design utilizes a shaft entirely fabricated of mild steel. The front 6 in. is protected with an overlay of Nicrocoat No. 3 alloy applied by the Nicrocoat Process. Processing is performed by Stainless Processing Division, Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich.

For details, circle No. 107 on Reader Information Card.

Magnesium Cleaner

The Bernard Chemical Products Co., 98–21 Linden Blvd., Ozone Park 17, N. Y., has announced the availability of a new compound—Bernite BR4— recently developed to clean the surface of magnesium so as to allow for spot welding and welding. This compound, reportedly, will remove dirt and all surface oxides leaving a mirror-like finish without changing the dimensions of the metal.

The compound is a dry powder and is used in concentrations of 1 to 1½ lb per gal of tap water for 2 min. There are no fuming, toxicity, heating or handling problems associated with its use.

For details, circle No. 108 on Reader Information Card.

Gas Tungsten-arc Unit

Compact design, simplified operation and low cost are features claimed for the new "Tig-Weld" 295 a-c welding unit by Emerson Electric Mfg. Co., 8100 Florrissant Ave., St. Louis 36, Mo.

Job Report Courtesy of Southwest Welding & Mfg. Division, Yuba Consolidated Industries, Inc., Alhambra, Calif.

When strong welds are needed to resist impact at minus 320°F

WELD WITH ARCOS

STAINLESS ELECTRODES

This six-section spherical liquid oxygen container is made of Type 321 stainless steel. Walls 4½" thick were required to withstand 3000 psi pressure. To assure crack-free welds to meet ASME impact properties at −320°F, it was welded with Arcos Chromend 19/9Cb-LC electrodes with controlled ferrite. The first time—and every time you use Arcos electrodes—you get top performance, save time, and money. ARCOS CORPORATION, 1500 South 50th St., Philadelphia 43, Pa.

For details, circle No. 26 on Reader Information Card

The excellence of one product over another is the result of imaginative research and precise quality. Fabricators of critical alloy steel weldments from atomic submarines to space missiles prefer the excellence of Alloy Rods Company products. With the introduction of a complete line of hard surfacing products, this preference is making itself known among companies demanding new standards of quality for wear resistant metal.

Alloy Rods Company

P. O. Box 1828, York, Pennsylvania

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semi-automatic wires
automatic wires
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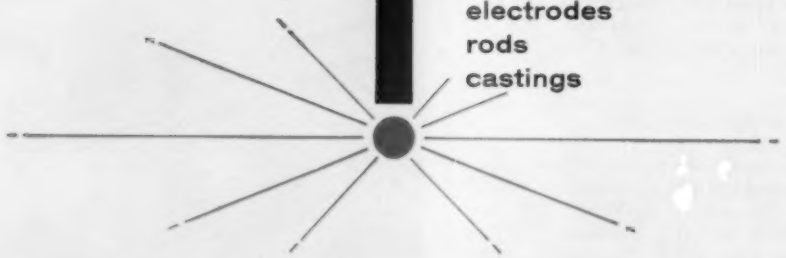


TWENTY YEARS OF LEADERSHIP IN THE DEVELOPMENT OF QUALITY ALLOY ARC WELDING ELECTRODES

For details, circle No. 27 on Reader Information Card

WELD-PAK
WELD-PAK
WELD-PAK
WEAR-ARC
WEAR-ARC

Designed for a welding range of 13 to 295 amp, this new a-c welder is said to provide economical operation in many applications such as truck, bus and boat repairs, new construction, tool and die shops, custom alloy fabrication and window frame construction. Its features include fully rated duty cycles for gas tungsten-arc welding—40% at 200 amp, or 30% at 295 amp; electrically controlled gas and water valves; high frequency intensity control; direct or remote operation; post flow control and pilot light.

For details, circle No. 109 on Reader Information Card.

Claims 100% Arc Stability

Model 425 ac-dc inert-gas welding machine is reported to have 100% arc stability to permit welding largest weldments down to fine wire. It is said to be particularly adaptable to welded-wire nodules, and is fully resonated. There are four overlapping current ranges from $^1/_2$ to 425 amp.

The machine has linearized current adjustment to prevent deadspots. Full rating operation is obtained from 208- and 460-v lines. The new design includes full power factor correction; phasing capacitors produce low line current at high welding currents.

Construction is to NEMA standards and is UL approved, according to manufacturer, Birdsell Division, Susquehanna Sciences, Inc., 350 N. Halstead, Pasadena, Calif.

For details, circle No. 110 on Reader Information Card.

180-amp Welding Machine

The twentieth Century Manufacturing Co., 9250 Access Rd., Minneapolis, Minn., has announced 180-amp dial control welding machine with accessories. Called the Model 71 Twentieth Century Welder, this new machine is said by the manufacturer to offer a range of

uses including soldering, welding, cutting, drilling holes, thawing water pipes, etc. Features include dial lifetime shunt control to reach any ampere setting desired, 80 open circuit voltage for easier arc striking and Class F insulation to withstand higher temperatures without breakdown and all steel construction with durable baked enamel finish.

For details, circle No. 111 on Reader Information Card.

New Large-size Split Sleeve

A new Smith split-sleeve in extra-long size, originally developed for a major oil company, has been announced by the Pipe Line Development Co., Cleveland, Ohio.

This sleeve has a 24 in. diam and is 54 in. long; it is designed for 950 psi maximum working pressure. The body is made of $1^1/_8$-in. thick firebox quality ASTM A-285 certified steel plate, grade C. The side bars are C-1020 hot rolled steel, and the bolts are $1^3/_8$-in. diam B-7 alloy steel. The nuts are C-1018 cold rolled steel, especially made with chamfered bottoms to facilitate seal-welding.

Ends of the sleeve are turned down for fillet-welding to pipe. Side bar spaces and bolts may be completely seal-welded, and welding may proceed with pipeline in service.

For details, circle No. 112 on Reader Information Card.

Free Samples Offered Antispatter Compound

Three spray products for conditioning metal surfaces have been introduced by Pacific Petrochemicals, Inc., Box 308, 5161 Triggs St., Los Angeles 22, Calif. Packaged in 16-oz aerosal containers are "Spatagon" an antispatter compound, "Anti Rust" for protection

of tools and machinery and "Micro-Finish" a cutting liquid for close machining operations. Full-size samples are offered on request.

'Spatagon" is said to simplify the problem of removing spatter after welding by forming a protective film. The spray is described as noninflammable—will not mix with water and may be painted over.

For details, circle No. 113 on Reader Information Card.

New Welding Goggles

Two new economical Ajax welding goggles, providing protection against a wide range of eye hazards, are are being marketed by Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y.

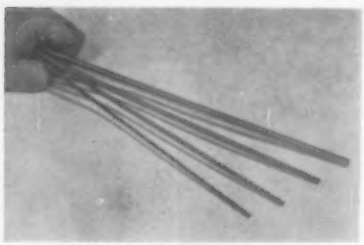
The Airco-Ajax gas welding goggle is recommended for use in gas-welding, cutting, burning and furnace operations, while the Ajax supercover goggle is recommended for wear over spectacles during similar operations. Both types of sturdy goggles have ventilated side-shields which keep out stray light and metal splashes and are designed to provide adequate ventilation to prevent lens fogging. Headbands are easily adjustable.

Eye cups for the Ajax gas-welding goggle are individually shaped with contoured surfaces for greater operator safety and comfort. Both goggles are available with shade No. 5 lenses only, which are graded for density and quality to meet commercial requirements.

For details, circle No. 114 on Reader Information Card.

Hard-surfacing Rods

Cast and centerless ground hard-surfacing rods made to exact customer specifications for maximum protection of metal parts against abrasion and corrosion conditions are now available from WaiMet Alloys Co., Division of Howe Sound Co., 5320 Oakman Blvd., Dearborn, Mich.



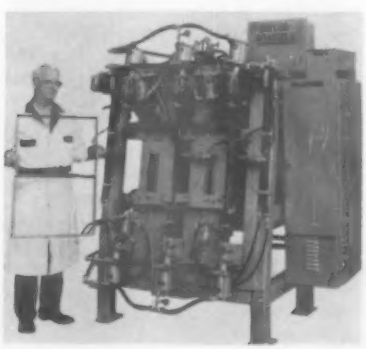
These rods reportedly are made to exact chemical specifications, usually within tighter chemistry limits than corresponding AWS specifications for the same typical composition. Rods are principally cobalt-base alloys with high percentages of tungsten, chromium and carbon and minor amounts of nickel. Other base metal types may be obtained to customer specifications.

The rods are centerless ground to a nominal dimension for bare rod applications and centerless ground to ±0.002 in. for electrode-covering extrusion.

For details, circle No. 115 on Reader Information Card.

Resistance-welding Machine for Windows

Basement window frames or sashes may be joined by hot upsetting or riveting with a resistance-welding machine now available from the Taylor Winfield Corp., 1048 Mahoning Ave., Warren, Ohio. Using this machine the 13 gage hot-rolled steel sections are held square and flat by air operated clamps. Vertical rail tongues engage in and protrude through lanced slots in the upper and lower rails.



Dual palm buttons initiate the automatic hot upsetting sequence; three 100-kva transformers are arranged to fire in sequence in order to reduce the power demand.

The machine is adjustable to handle a variety of window frames and sash by means of a hand screw which raises a plate carrying the three lower welding guns, clamping air cylinders and locating blocks. The center pair (upper and lower) of welding guns used for welding the sash center post, are inoperative when producing window frames.

For details, circle No. 116 on Reader Information Card.

Storage Boxes

Pipe-beveling machine storage boxes manufactured by H&M Pipe Beveling Machine Co., Tulsa, Okla. are now being built from aluminum instead of steel which, according to company officials, reduces the weight of the boxes by approximately two-thirds.

The new boxes provide the same strength and protection as the old steel models with the added advantages that they require no painting and there is no danger of rusting.

The boxes have special fittings to hold the pipe beveling machine and torch in place and are designed to protect the machines from the effects of weather and handling damage when they are not in use.

For details, circle No. 117 on Reader Information Card.

Single Generator for Low and High Frequencies

In line with a continuing campaign to build increased versatility into all of its units, Induction Heating Corp., Brooklyn, N. Y., has introduced a new Ther-Monic 30-kw generator capable of producing power at both high and low frequencies. By merely flicking the selector switch the unit can be operated at low frequencies of from 250 to 450 kc, and from 1 to 7 mc.

All controls have been built into the unit and are operated externally. The generator can be adapted to such diverse applications as soldering, brazing, annealing and hardening. A variable out-put transformer for low-frequency operations, and a completely adjustable tank for those jobs requiring high-frequency heating, are housed in the completely dust-tight cabinet. The generator is also equipped with a saturable reactor for controlled output, and can be constructed with Thryton-controlled output. Heat exchangers for water and cabinet cooling are all built in.

For details, circle No. 118 on Reader Information Card.

Storage for Seam Welding

A steel belt conveyer at the Vulcan Container Corp., Bellwood, Ill., provides live storage for pails and drums awaiting seam welding. Manufactured by Sandvik Steel, Inc., Fair Lawn, N. J., the belt is made of a strip or band of carbon steel, especially trued and flattened at the mill for conveyer application.

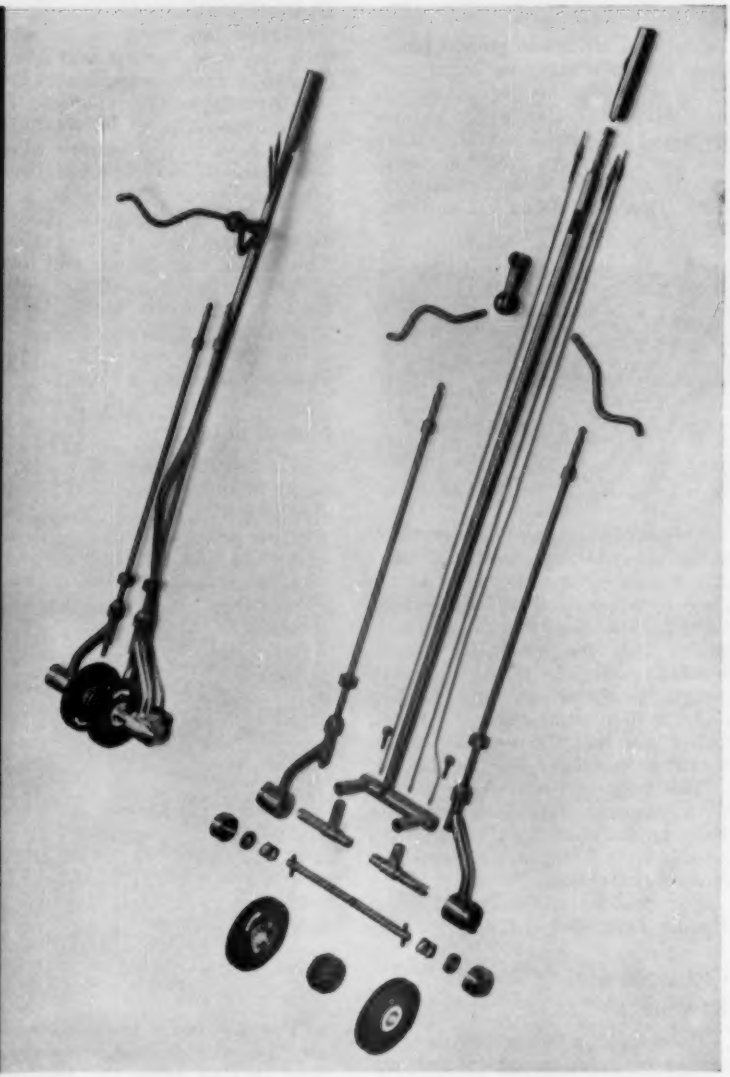
The belt conveys the cylindrical shells of the steel shipping containers from a tack welding machine to a continuous seam welding operation. When the lead item is removed for welding, the others automatically move up to await their turn. Conveyer side skirts are adjustable for different sized containers.

The conveyer is of the "Tru-Track" type and has a V-rope bonded to its underside. This V-rope assures continuous perfect tracking and eliminates the need for terminal drums and the possibility of catching stray items between the belt and drum.

For details, circle No. 119 on Reader Information Card.

HERE'S HOW STILL ANOTHER MANUFACTURER JOINS STAINLESS STEEL TUBING:

He uses Handy & Harman's BRAZE 630



He's one of many manufacturers and fabricators who have found—to their lasting satisfaction—that Handy & Harman silver alloy brazing is the final answer to stainless steel joining problems.

Super-Donic Manufacturing Company, Atlanta, Georgia, manufactures "Dual Arm Transmissions" for the dental industry. Most everybody has—at one time or another—seen and/or felt this unit in operation.

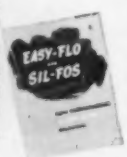
It is fabricated of small diameter 304 and 316 stainless steel tubing and, in its assembled form, consists of some 17 separate brazed joints. Joints must be strong, corrosion resistant and neat-appearing.

Each of the 17 joints is hand-torch brazed with Handy & Harman BRAZE 630 wire and HANDY FLUX TYPE B-1. There's no question that this is a unique application. There's no question, either, that the application is stainless steel. The ease and economy with which this manufacturer solves his problems can be just as readily applied to *your* stainless steel joining problems.

Strength, production speed, electrical and thermal conductivity, gas and liquid tightness and low cost are *natural* benefits of silver alloy brazing. We think it worth your while to learn more about this remarkable metal-joining method—we'll be glad to send you any information you ask for. Handy & Harman, 82 Fulton St., New York 38, N. Y.

FOR A GOOD START: BULLETIN 20

This informative booklet gives a good picture of silver brazing and its benefits... includes details on alloys, heating methods, joint design and production techniques. Write for your copy.



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For details, circle No. 28 on Reader Information Card

UNIONARC

REDESIGNED...REBUILT...RELIABLE

Development of a LINDE welding process does not stop with its introduction. In the past 18 months, we have invested over 3000 laboratory manhours to further improve the UNIONARC welding process and equipment. New: portable UAM-2 machine, simplified UAW-2 torch, refined consumables. Improved equipment for an improved CO_2 steel welding process, featuring

- **...wear-resistant flux and wire-guide tubes, super-hard "Stellite" torch body**
- **...automatic flux-CO_2 shutoff valve for precise flow of consumables**
- **...stainless-steel hopper funnel for smooth flux feed**
- **...serrated V-groove drive roll (patent pending) for positive wire feed**
- **...miniature machine—300 lbs. lighter, uses 50% less space**
- **...refined flux that increases metal deposition rates**
- **...proven results: dependable operation with minimum maintenance.**

For field-tested application details, see next page

UNIONARC

Portable machine . . . produces 30-ipm . . . top-quality welds

One of the nation's largest construction-equipment manufacturers field-tested 15 UNIONARC UAM-2 machines full time—three shifts a day, six days a week—over 2000 hours per week. Maintenance has averaged less than ½ hour per machine per week, a downtime factor of less than 0.5 per cent. This is tested reliability that insures process advantages:

- . . . cost as low as 27¢/lb. of metal deposited
- . . . deposition rates as high as 25 lb./hour
- . . . speed over 30 ipm on ¼ in. carbon-steel fillets
- . . . quality to strictest specifications—ASME, Military, Bureau of Shipping
- . . . full penetration requiring less preparation, fewer passes, less wire.

On a production basis, these advantages mean substantial savings. A western pipe manufacturer saved 25¢/ft. of weld on 28,000 feet of welds. A southwestern fabricator reduced welding time on three on-site storage tanks (9500 ft. of welds) from 1850 manhours to only 700 manhours. A northern manufacturer eliminated expensive reworking of code assemblies, gained 100% weld acceptance with UNIONARC compared to 50% to 90% with covered electrodes. A mid-western manufacturer eliminated beveling, and reduced pass and wire requirements on Schedule 40 pipe by 2:1 and 3:1 ratios respectively.

UNIONARC welding is an ideal process for carbon steel. On a production basis, it is unquestionably faster and more economical than other CO_2 or covered electrode processes. It uses a wide range of readily-available, low-cost wires that meet any application need. It uses one flux, one low-cost CO_2 shielding gas. It has the speed and weld quality of manual submerged-arc welding, with the advantage of weld visibility. It is a sound, well-engineered process designed primarily for repetitive, high-production work on carbon steel. For these applications, the new UNIONARC UAM-2 machine offers outstanding cost advantages with a field-proven low-maintenance factor that produces clear-cut profit for its user. For detailed information or a live demonstration, call your nearest LINDE office.

"Linde," "Unionarc" and "Union Carbide" are registered trade marks of Union Carbide Corporation

LINDE COMPANY

UNION CARBIDE

Division of Union Carbide Corporation
270 Park Avenue, New York 17, N. Y.

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4	29	54	79	104	129
5	30	55	80	105	130
6	31	56	81	106	131
7	32	57	82	107	132
8	33	58	83	108	133
9	34	59	84	109	134
10	35	60	85	110	135
11	36	61	86	111	136
12	37	62	87	112	137
13	38	63	88	113	138
14	39	64	89	114	139
15	40	65	90	115	140
16	41	66	91	116	141
17	42	67	92	117	142
18	43	68	93	118	143
19	44	69	94	119	144
20	45	70	95	120	145
21	46	71	96	121	146
22	47	72	97	122	147
23	48	73	98	123	148
24	49	74	99	124	149
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5	30	55	80	105	130
6	31	56	81	106	131
7	32	57	82	107	132
8	33	58	83	108	133
9	34	59	84	109	134
10	35	60	85	110	135
11	36	61	86	111	136
12	37	62	87	112	137
13	38	63	88	113	138
14	39	64	89	114	139
15	40	65	90	115	140
16	41	66	91	116	141
17	42	67	92	117	142
18	43	68	93	118	143
19	44	69	94	119	144
20	45	70	95	120	145
21	46	71	96	121	146
22	47	72	97	122	147
23	48	73	98	123	148
24	49	74	99	124	149
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Index to ADVERTISERS

PAGE	
47	Acro Welder Mfg. Co.
9	Air Products Incorporated
Outside Back Cover	Air Reduction Sales Company
50	All-State Welding Alloys Co., Inc.
98–99	Alloy Rods Company
96–97	Arcos Corporation
88	Bateman Foundry & Machine
75	Chicago Hardware Foundry Company
48	Detroit Stamping Co.
7	Eastman Kodak
61	Falstrom Company
5	General Dynamics Corp. Liquid Carbonic Div.
102	Handy & Harman
3	Hobart Brothers Company
88	Instrument Control Company
10	International Nickel Co., Inc.
Inside Front Cover	Jackson Products
76	Lenco, Inc.
81–86	The Lincoln Electric Company
103–04	Linde Company, Division of Union Carbide Corporation
5	Liquid Carbonic Division General Dynamics Corp.
12	Miller Electric Mfg. Co., Inc.
92–93	National Cylinder Gas
88	NRC Equipment Corporation
80	North and Weininger
75	Royco Instruments Inc.
87	Tec Torch Co., Inc.
10	Tempil® Corporation
74	Tuffaloy—Air Reduction Sales Co.
103–04	Union Carbide Corporation Linde Company
Inside Back Cover	Victor Equipment Company
10	Wall Colmonoy Corporation
89	Wallson Associates

Welding Research

Sponsored by the Welding Research Council of the Engineering Foundation

WRC

SUPPLEMENT TO THE WELDING JOURNAL, JANUARY 1961

Studies of Hot Cracking in High-Strength Weld Metals

Use of freezing-cycle hot-tension machine indicates combined sulfur-phosphorus content below 0.025% prevents hot cracking

BY H. W. MISHLER, R. E. MONROE AND P. J. RIEPPEL

ABSTRACT. The study of hot cracking in high-strength weld metals has been active for several years. This type of cracking occurs as the weld deposit cools just below the solidus temperature. By the use of the freezing-cycle hot-tension machine, the effects of various elements on the tensile properties of SAE 4340 weld metals have been studied at the temperatures at which hot cracking occurs. The results obtained in previous studies have disclosed that a combination of high sulfur and phosphorus contents, even though within existing specification limits, greatly reduces the freezing-cycle hot-tensile strength and ductility. This decrease in strength properties at temperatures just below the solidus also was related to poor hot cracking resistance of the weld metal.

Freezing-cycle hot-tension studies were concerned with (1) obtaining data supplementary to those previously obtained to establish a maximum limit on phosphorus content, (2) determining a similar limit for sulfur, and (3) studying the combined effect of sulfur and phosphorus. The maximum permissible phosphorus content to maintain good freezing-cycle hot-tensile properties appears to be in the range of 0.017 to 0.020%. This limit was established in the presence of 0.005% sulfur. A similar limit on sulfur was determined with a phosphorus content of 0.010%. It is possible that the sulfur limit would be higher if the phosphorus could have been maintained at a lower level. The effects of the two elements appear to be roughly additive below a total content of 0.025%. If the total sulfur and phosphorus contents of SAE 4340 steel are kept below about 0.025%, good hot ductility and hot strength are obtained. With good hot-tensile properties, then, good resistance to hot cracking is expected.

Metallographic examination previously conducted of a high-phosphorus SAE 4340 steel disclosed the existence of an intergranular phase of unknown composition. By a combination of light microscope and electron-microscope examination, this unknown phase was identified as an iron–iron phosphide (Fe_3P) eutectic.

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Introduction

The performance and success of current aircraft and missiles depend to a great extent on the material from which they are constructed. The weight savings resulting from the use of higher-strength materials are responsible for the ever-increasing speed and load-carrying capacity of these vehicles. Since the requirements of future designs are constantly being raised, there is a continual quest for materials of higher and higher strength-to-weight ratios. As a result of such a trend, it has been natural to turn from the light metals to the very high-strength steels. No material, however, can be considered satisfactory for use in flight vehicles unless it can be fabricated into components. One of the prime considerations as to the fabricability of a steel is its weldability.

The use of ultra-high-strength steels in these applications has been hampered by several problems occurring in the welding of these steels, chief among these being weld-metal cracking. The major type of cracking associated with weld metal is hot cracking, which occurs as the weld deposit cools just below the solidus temperature. Under the sponsorship of the Wright Air Development Division, a series of studies of the causes of hot cracking in high-strength weld metals has been conducted for several years. It was observed in these studies[1,2] that weld metals prone to hot cracking have poor strength and ductility in the temperature range of 2700 to 2000° F. By the use of the freezing-cycle hot-tension machine, the strength properties of the weld metal in this temperature range may be determined accurately and the hot-cracking susceptibility of the weld metals may be predicted. Since it is known that sulfur affects the hot-cracking tendency of a weld metal, weld deposits of SAE 4340 composition with varying sulfur contents have been the chief object of study. Phosphorus also occurs as an impurity in this steel

Table 1—Chemical Composition of Experimental Heats of Steel

Heat	Chemical composition, % C	Mn	P	S	Si	Ni	Mo	Cr
15	0.43	0.86	0.017	0.006	0.33	1.86	0.26	0.85
17-A	0.40	0.58	0.009	0.031	0.25	1.71	0.24	0.80
DE-AA1	0.40	0.70	0.004	0.004	0.33	1.91	0.27	0.78
DE-AA2 split heat	0.40	0.70	0.020	0.004	0.33	1.91	0.27	0.78
DE-AA3	0.40	0.70	0.089	0.004	0.33	1.91	0.27	0.78
DE-M1	0.38	0.72	0.019	0.003	0.36	1.86	0.23	0.79
DE-M2 split heat	0.38	0.72	0.020	0.013	0.36	1.86	0.23	0.79
DE-M3	0.38	0.72	0.025	0.013	0.36	1.86	0.23	0.79
DE-N1	0.38	0.72	0.010	0.012	0.41	1.85	0.24	0.78
DE-N2 split heat	0.38	0.72	0.010	0.023	0.41	1.85	0.24	0.78
DE-N3	0.38	0.72	0.029	0.023	0.41	1.85	0.24	0.79

in roughly the same amount as sulfur, so the effects of this element also have been studied.

Results of these past freezing-cycle hot-tension tests have indicated that either of these two elements in amounts in excess of 0.010% progressively lower the hot strength and ductility of the weld metal as its content increases. The sulfur and phosphorus form low-melting-point intergranular phases, which are responsible for the decreased strength properties at the temperatures at which hot cracking occurs; above 1800° F these phases may be either molten or have very low ductility. Thus, as the weld metal contracts on cooling, failure occurs in the grain boundaries. On further cooling, these intergranular failures may remain small (microcracks) or may propagate and form much larger hot cracks. Failure of the entire weldment may occur in service at some future time due to the stress concentrations caused by these weld-metal flaws. This is especially true if the material is heat treated to very high-strength levels wherein resistance of both the weld metal and parent material to crack propagation is low.

The freezing-cycle hot-tension studies reported in this paper had as an objective the obtaining of additional information on the effect of sulfur and phosphorus on the hot-strength properties of SAE 4340 weld metal. In addition, the combined effects of sulfur and phosphorus were studied.

Materials

The experimental steels used in this study were prepared in the foundry at Battelle. Since the amount of residual elements in these heats would be varied only slightly from heat to heat, special care was required in the preparation of the steels. Electrolytic iron was used as the melting stock. Melting was by induction in an MgO crucible under an argon atmosphere to prevent oxidation.

Chemical analyses of these steels are given in Table 1. These analyses were made of the ingots prior to hot working. The ingots subsequently were hot-forged and rolled to round stock. Specimens for the freezing-cycle hot-tension tests were machined from this round stock.

Test Procedure

The strengths and ductilities of the weld metals in the temperature range under consideration were determined by the use of the freezing-cycle hot-tension machine illustrated in Fig. 1 and shown schematically in Fig. 2. This machine may be used to test specimens at temperatures from the solidus down to room temperature. The center of the specimen in Fig. 3 is melted and then allowed to cool to a predetermined temperature and fractured. The load for fracturing the specimen is applied by an air cylinder at the top of the apparatus. The specimen is attached to an extension rod from the piston in the cylinder. The piston is activated by air pressure supplied by a compressor. The control valve for the air cylinder is pilot-operated so that the same rate of loading of the piston may be maintained for each test. To prevent a large drop in operating air pressure when the valve is opened, an accumulator is used in the supply line. The load applied to the specimen is measured on a high-speed recorder from strain gages placed on a load cell connected to the lower extension rod. The ductility of the specimen is determined by measuring the reduction of area.

The specimen is heated by a $4^1/_2$-turn induction coil placed around the specimen at its midpoint and connected to a 30-kw spark-gap induction heater. Approximately 20 sec are required to heat the specimen to 2900° F. The molten metal is retained by a quartz sleeve around the specimen. A clearance of about 0.005 in. is maintained between the quartz sleeve and the specimen. Since the specimen expands more than does the sleeve on heating, this clearance is necessary to prevent cracking of the sleeve. Water-cooled copper blocks are clamped to each end of the specimen just outside the molten zone to obtain axial heat flow away from the center of the specimen as it cools. The cooling rate of the specimen and the heat flow away from the molten zone are similar to those occurring in an actual weld. Thus, this specimen is an accurate representation of a weld joint.

The temperature of the specimen is measured by placing a platinum–platinum-10% rhodium thermocouple in the molten zone. The thermocouple is inserted through a hole drilled along the center line of the specimen. It is protected from the molten metal by a ceramic tube closed at one end. Temperature is indicated by a high-speed temperature recorder (1-sec response for full scale). The thermocouple well is approximately $3^3/_{32}$ in. deep. Since the cap on the end of the protection tube is about $^3/_{32}$ in. deep, the thermocouple bead thus is positioned at the center of the specimen. By matching the depth of the hole to the length of the

Table 2—The Effects of Sulfur and Phosphorus Contents on the Hot-cracking Susceptibility of SAE 4340 Weld Metals

Heat[a]	Sulfur content, %	Phosphorus content, %	Total sulfur and phosphorus contents, %	Minimum level of restraint to develop hot cracks,[b] in.
2	0.008	0.005	0.013	>8
17-C	0.014	0.007	0.021	$6^1/_2$
15	0.006	0.017	0.023	6
11-A	0.015	0.012	0.027	$5^1/_2$
17-B	0.025	0.007	0.032	3
17-A	0.031	0.007	0.036	2
13	0.007	0.039	0.046	$1^1/_2$
12-A	0.036	0.011	0.047	$1^1/_2$

[a] These heats of steel were produced under previous research.
[b] As determined by the standard Lehigh test.

Fig. 1—Freezing-cycle hot-tension machine and auxiliary equipment

protection tube, the amount of air space at the end of the well is minimized. If an excess of air were present, the air would expand on heating and cause a large void in the center of the specimen when melting occurs. Some variation of cap thickness of the protection tube existed. Tests were made to determine whether the increased thickness of some of the caps would affect the temperature indications. However, no variation of temperature measurement occurred.

Some modifications have been made to the apparatus from that indicated in Fig. 1. The air pressure necessary for the test is supplied by an air compressor rather than by the bottled nitrogen shown in the photograph. Also, the photograph indicates the use of a clip-gage extensometer for measuring the elongation and, thus, the ductility of the specimen. As mentioned previously, specimen ductility now is determined from the reduction of area. Reduction of area is a more accurate means of determining ductility since the specimen length over which elongation would occur varies depending on the test temperature used.

Effects of Phosphorus

Studies were conducted to determine the effect of phosphorus on the hot strength and ductility of SAE 4340 weld metal. Two heats of simulated weld metal with low sulfur and varying phosphorus contents were prepared and tested (Heats DE-AA1 and AA2). The high-temperature strength and ductility of the low-phosphorus (0.004%) heat of this series (Heat DE-AA1) were excellent—Fig. 4. However, when the phosphorus was increased to 0.020% (Heat DE-AA2), the hot ductility and strength dropped to a lower level. The properties of these heats are shown in Fig. 4. The hot ductility of another heat of SAE 4340 steel (Heat 15) which had a phosphorus content of 0.017% was nearly the same as that of Heat DE-AA1. Thus, a phosphorus content of 0.017% appears to be very near the maximum limit for phosphorus since a large drop in the hot ductility of the weld metals occurs between 0.017 and 0.020% phosphorus.

Heat DE-M1 was prepared with a phosphorus content planned to fall between 0.017 and 0.020%. The actual content was 0.019%. The hot-ductility characteristics are intermediate between those of Heats 15 and DE-AA2 being somewhat closer to the ductility curve of DE-AA2. In the range of phosphorus contents between 0.017 and 0.020%, a marked deterioration of the hot-ductility characteristics of the weld metal occurs. The maximum phosphorus content permissible in SAE 4340 weld metals, then, would be within this range. Weld metals with phosphorus contents greater than this limit would have unsatisfactory hot-ductility properties. The resistance to weld-metal hot cracking of Heat 15 was previously determined. The minimum level of restraint necessary to develop hot cracks in Heat 15 weld deposit measured by the standard Lehigh test[2] was found to be 6 in. This is considered to be a moderate level of restraint and is felt to be just acceptable. Since

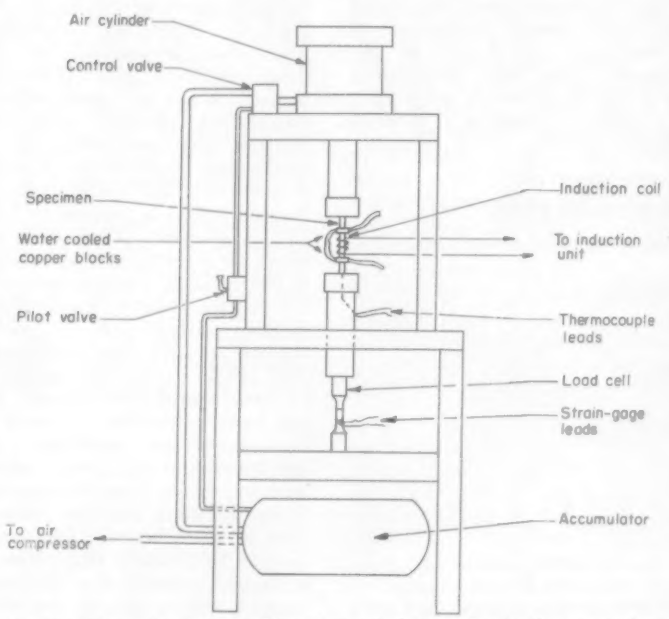


Fig. 2—Schematic diagram of freezing-cycle hot-tension testing apparatus

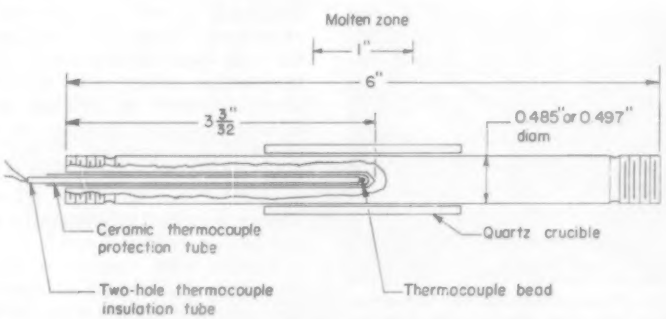
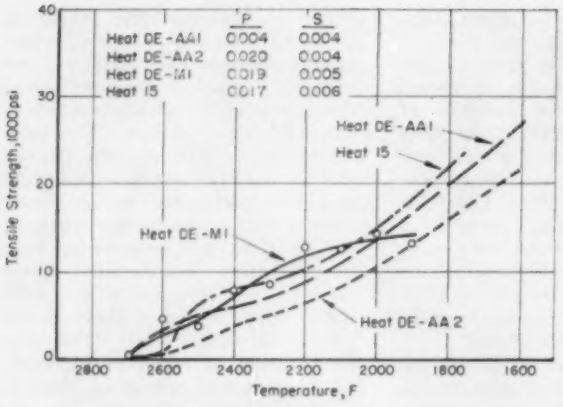


Fig. 3—Hot-tension specimen. Diameter of specimen depends on inside diameter of quartz sleeving used to retain molten metal. For clarity, the diameters of the thermocouple insulation, protection tube and hole are not to scale



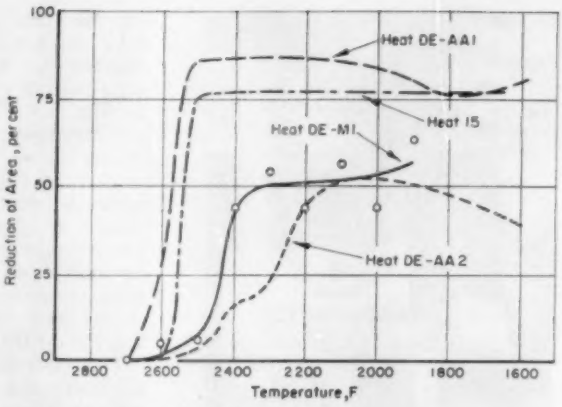


Fig. 4—Comparison of the effects of phosphorus content on the hot strength and ductility of SAE 4340 weld metal

weld metals with phosphorus contents greater than those of Heat 15 have progressively poorer hot-ductility characteristics, they also would have poorer resistance to hot cracking. It should be remembered that this phosphorus limit is for weld metals with very low sulfur contents (around 0.005%).

Identification of Intergranular Phase

The amount of sulfur and phosphorus present in SAE 4340 weld metal has been shown to cause a decrease in the hot strength and ductility as measured by the freezing-cycle hot-tension equipment. The exact mechanism by which these elements affect hot-tension properties has not been definitely established. However, many investigators have maintained that this mechanism involves the formation of a low-melting intergranular film. If such a film is present in a large enough quantity, it can have a bad effect on the strength and ductility of the metal at temperatures above the melting point of the constituent making up this film. In previous studies of the microstructure of SAE 4340 steels, the existence of an unidentified intergranular phase has been established in steels with high-phosphorus contents. Since the amount of this phase increased with increasing phosphorus content, it was believed that the phase was rich in phosphorus. Previous attempts to identify this phase had been unsuccessful, and further attempts were made in the current program.

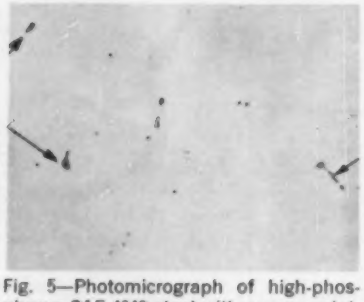


Fig. 5—Photomicrograph of high-phosphorus SAE 4340 steel with arrows pointing to intergranular phases—light picral plus Murakami's etchant—× 500 (reduced 50% on reproduction)

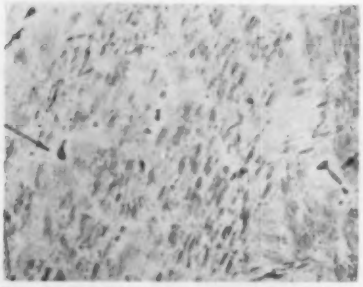


Fig. 6—Photomicrograph of high-phosphorus SAE 4340 steel showing microstructure of the steel and with arrows pointing to intergranular phases—picral plus HCl etchant—× 500 (reduced 50% on reproduction)

The microstructure of a high-phosphorus heat of SAE 4340 (Heat DE-AA3, 0.089% phosphorus) was examined. This heat was selected for this examination since the intergranular phase was present in large amounts as related to the high-phosphorus content. A series of photomicrographs of the same field in the microstructure of this steel is shown in Figs. 5 and 6. The unidentified intergranular phase can be seen in Figs. 5 and 6.

Studies with various etches and the light microscope showed that the unknown phases were darkened or stained by Murakami's etchant. Such behavior is an indication of the presence of iron phosphide (Fe_3P).[3] The structure of this phase could not be resolved sufficiently with the light microscope to estimate the amount of iron phosphide present in the phase. However, using the electron microscope, the structure of the phase was resolved as shown in the electron micrographs that appear in Figs. 7 and 8. These micrographs show that the phase has a eutectic structure. Since the phase is known to contain iron phosphide and since it has a eutectic structure, the intergranular phase is probably the iron-rich alpha-solid solution-

Fig. 7—Electron micrograph of intergranular phase in high-phosphorus SAE 4340 steel—picral plus HCl etchant—× 6250 (reduced 50% on reproduction)

Fig. 8—Electron micrograph of intergranular phase in high-phosphorus SAE 4340 steel wherein area in lower right corner is a tear in the replica—picral plus HCl etchant—× 8750 (reduced 50% on reproduction)

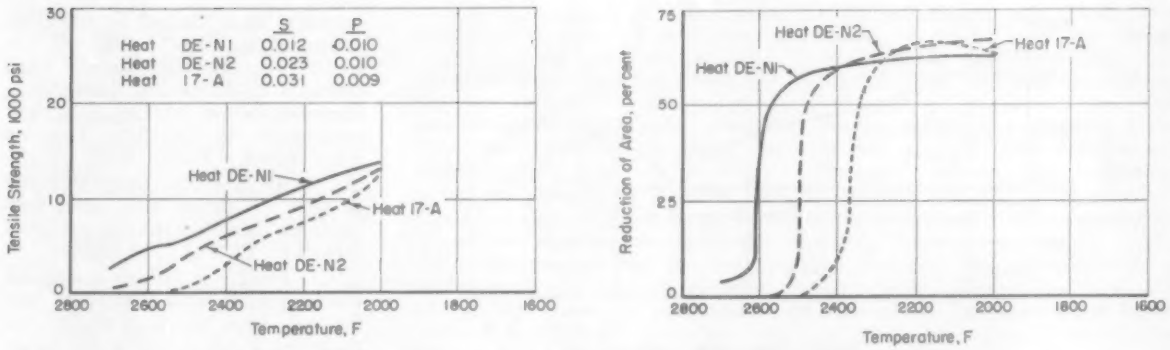


Fig. 9—Comparison of the effects of sulfur content on the hot strength and ductility of SAE 4340 weld metal

iron-phosphide eutectic. This eutectic contains 10.2% by weight of phosphorus and melts at 1920° F (1050° C.) The identification of this intergranular phase seems to support the previous assumption that SAE 4340 steels with a high-phosphorus content contain an intergranular eutectic film. Although it is not apparent in the micrographs shown, the iron-iron phosphide eutectic phase is segregated along grain boundaries. Since this phase freezes at a very low temperature, the hot strength and ductility of steel containing an appreciable amount of this eutectic would be lowered.

Effects of Sulfur

Although it had been learned that a sulfur content greater than 0.010% will affect the high-temperature strength and ductility of SAE 4340 weld metal, no maximum limit had been determined for sulfur content. Heats DE-N1 and DE-N2 were prepared for use in an effort to establish a limit on sulfur content through the study of the freezing-cycle hot ductility and strength of these two simulated weld metals. The sulfur contents were 0.012 and 0.023% respectively, and the phosphorus content of both heats was 0.010%.

The hot-ductility characteristics of these two heats are shown in Fig. 9. The curves previously obtained for Heat 17-A which has a high-sulfur content (0.031%) also have been included. The hot strengths of these three heats progressively decrease as the sulfur content increases. The sulfur content also affects the hot-ductility characteristics. Above 2300° F, the ductility of Heat 17-A drops off very rapidly. Heat DE-N2, with a lower-sulfur content, maintains good ductility to 2500° F. A further decrease in sulfur content, as in heat DE-N1, allows good ductility to be obtained at about 2600° F.

On the basis of results from these three heats, it is rather difficult to set a limit on the amount of sulfur permissible in SAE 4340 steel. Previously conducted cracking tests have indicated that the sulfur content must be held to about 0.015% to obtain satisfactory resistance to hot cracking. The minimum amount of restraint necessary to develop hot cracks in weld deposits with this sulfur content

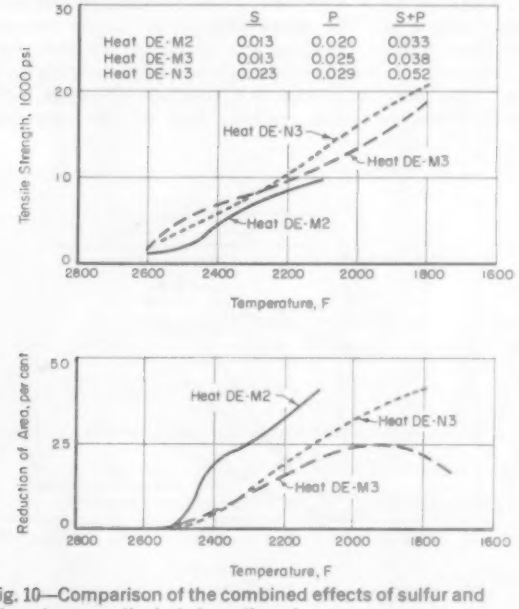


Fig. 10—Comparison of the combined effects of sulfur and phosphorus on the hot strength and ductility of SAE 4340 weld metal

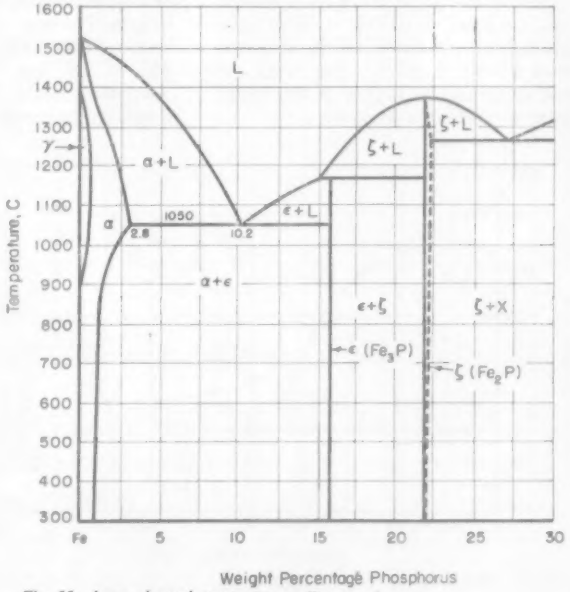


Fig. 11—Iron-phosphorus phase diagram[5]

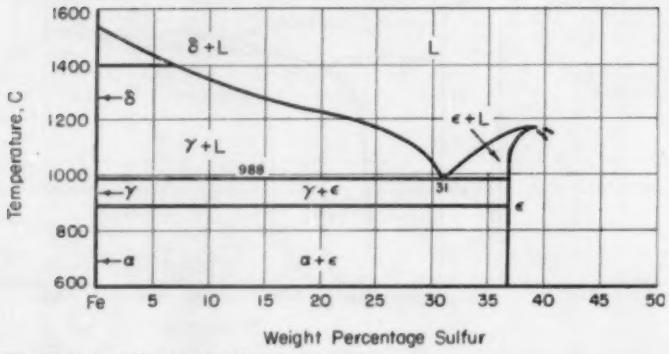


Fig. 12—Iron-sulfur phase diagram[3]

is about 6 in. as measured by the Lehigh test. (Weld metals which develop hot cracks at levels of restraint lower than 6 in. are considered unsatisfactory.) The sulfur contents of Heats DE-N1 and DE-N2 would cause unsatisfactory cracking resistance on this basis. However, both of these heats develop quite good hot ductilities, although there is a difference of about 100° F between the temperatures at which the high ductilities are achieved. Heat DE-N1 also has better strength characteristics than does Heat DE-N2. Since it is assumed that Heat DE-N1 would have good cracking resistance and Heat DE-N2 would not, it would appear that a weld metal must obtain good ductility by the time it cools to 2600° F or slightly below in order that it have good resistance to hot cracking. Thus, the maximum limit for sulfur in SAE 4340 weld metal appears to be about the same as for phosphorus, i.e., around 0.017%. Since the phosphorus content of these heats was about 0.010%, the limit on sulfur might be higher if the phosphorus content were lower.

Effects of Combined Sulfur and Phosphorus

The limits indicated above for sulfur and phosphorus should be considered only when the content of the other two residual elements is very low. The question naturally arises as to what limits should be exercised when an appreciable amount of both phosphorus and sulfur is present. It has been surmised in the past that the effects of these two elements are additive. The freezing-cycle hot-tension properties of Heats DE-M2, DE-M3 and DE-N3 were determined in the hope that the results perhaps would help to confirm this premise. The strength and ductility curves for these three heats are given in Fig. 10.

The hot ductilities of Heats DE-M3 and DE-N3, which have high total sulfur and phosphorus contents (0.038 and 0.052%, respectively) are poor. Improved ductility is obtained when the total content is reduced to 0.033% in Heat DE-M2. As the total content is decreased still further, the hot-ductility characteristics continue to improve, as indicated by the data presented in Figs. 4 and 10. It should be noted that as the total contents of sulfur and phosphorus decrease below 0.025%, the improvement in ductility becomes more rapid. Below 0.023%, the hot-tensile properties have improved to such an extent that good hot-cracking resistance may be expected (Heats 15, DE-AA1 and DE-N1).

The results of Lehigh restrained weld-cracking tests that were conducted during previous studies are given in Table 2. If a minimum level of restraint to develop hot cracks of 6 in. or greater is taken as the criterion for good cracking resistance, then only those filler wires with total sulfur and phosphorus contents of less than about 0.025% are acceptable. The results from both the freezing-cycle hot-tension tests and the restrained weld-metal cracking tests indicate that when the combined sulfur and phosphorus contents of a filler wire reach the range of 0.020 to 0.025% or greater, the hot-tension properties deteriorate and the resistance to weld-metal hot cracking drops below the minimum acceptable level.

Wilkinson, Cottrell, and Huxley[4] also have observed that, for a steel of this type, the total sulfur and phosphorus contents should be kept below about 0.025% to prevent hot cracking in thin (less than 1/8 in.) sheet. The limits on sulfur and phosphorus that were discussed in the two previous sections fall below this range. However, it should be remembered that in specifying these limits consideration was given to the fact that the materials used in studying each of the two residual elements were not entirely free of the opposing

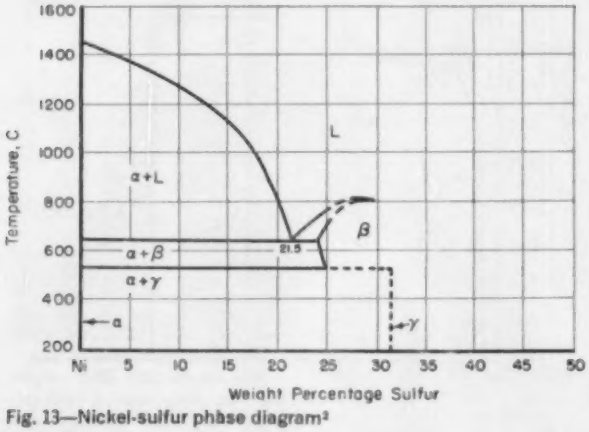


Fig. 13—Nickel-sulfur phase diagram[3]

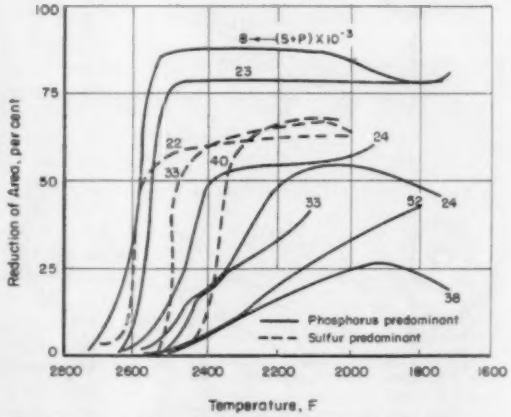


Fig. 14—Comparison of the effects of predominant sulfur or phosphorus on the freezing-cycle hot ductility of SAE 4340 weld metal

element. At each of the specified limits, the total sulfur and phosphorus contents fell roughly in the range of 0.020 to 0.025%.

Discussion

In analyzing the freezing-cycle hot-tension study data, several observations worthy of comment were made. These comments apply to SAE 4340 weld metal and may, or may not, apply to other steels of this type. The effects of sulfur and phosphorus on the hot-ductility behavior appear to be somewhat different. Increasing the sulfur content decreases the temperature at which ductility is obtained but does not affect the ultimate ductility. Increasing the phosphorus content, however, decreases both the temperature at which ductility is obtained and the ultimate ductility. The phosphorus content also affects the transition rate from low ductility to the ultimate ductility. At the higher phosphorus contents, a slower transition rate is observed. Sulfur does not appear to affect the transition rate. This difference in observed behavior may be a reflection of the differences in the phase diagrams of the elements probably responsible for poor high-temperature properties. Assuming that with phosphorus the responsible phase is the iron–iron phosphide eutectic, then the phase diagram shown in Fig. 11 applies.* With sulfur, either iron or nickel may be involved in a eutectic with sulfur as shown in Figs. 12 and 13. Referring to Fig. 11, it can be seen that upon solidification, an iron-rich solid solution containing a maximum of 2.8% phosphorus will form along with the eutectic between the solid solution and iron phosphide (Fe_3P). As the phosphorus content increases, the solid solution becomes more enriched in phosphorus and the behavior of any phosphorus-rich film would be expected to exhibit a transition rate reflecting the change in matrix properties with changing phosphorus content. Referring to either Figs. 12 or 13, it can be seen that no similar solid solutions exist in the sulfur phase diagrams. Therefore, upon solidification, only iron or nickel and the eutectic between iron and nickel and either iron sulfide or nickel sulfide would form. Since no change in sulfur solubility occurs, no rate change in transition behavior with changing sulfur content would be expected. Instead, increasing the sulfur content would be expected to merely lower the effective melting temperature of any intergranular film.

This analysis and the data presented showing the effects of varying phosphorus contents on hot-tension properties of very low-sulfur steels appear to dispute the accepted idea that the main effect of phosphorus in relation to weld-metal cracking is in its influence on sulfide distribution. In fact, it now appears that the general belief that sulfur is the prime bad actor in weld-metal cracking may be erroneous. Phosphorus appears to deserve that distinction, although certainly either element is to be avoided. While it has been stated that a limit of 0.020 to 0.025% combined sulfur and phosphorus should be set to avoid weld-metal cracking, this is merely an expedient. The effects of the two elements on hot-tension properties are not strictly additive, and again phosphorus appears more detrimental. However, above the maximum allowable limit, the question of relative potency is merely academic. Figure 14, which combines all the hot-ductility curves presented in this paper, shows the more pronounced effect of phosphorus, but it should be remembered that only the three left-hand curves represent acceptable behavior.

* See the section on phase identification for support of this assumption.

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An Important Reminder

AUTHORS...

January 15, 1961, is the deadline when application forms and abstracts must be postmarked in order to receive consideration for presentation at the 1961 AWS National Fall Meeting to be held in Dallas, Tex., Sept. 25–28, 1961.

The application form was included as a detachable insert in the October issue of the WELDING JOURNAL. Additional copies of the application, as well as "Instructions and Suggestions for Authors," may be obtained by writing to AWS headquarters, 33 W. 39th St., New York 18, N. Y.

Properties of Plasma-Sprayed Materials

Laboratory investigation demonstrates that the highest-melting-point materials can be sprayed successfully with arc-plasma equipment

BY M. A. LEVINSTEIN, A. EISENLOHR AND B. E. KRAMER

ABSTRACT. New arc-plasma equipment for the spraying of metallic and nonmetallic materials is briefly described, including one gun for powders and another for wire. With the arc plasma as a heat source, the highest-melting-point materials can be sprayed. With this equipment, specimens were prepared for the determination of selected physical and mechanical properties of arc-plasma deposited materials.

The materials investigated were tungsten, molybdenum, hafnium carbide, tantalum carbide, cerium oxide and hafnium oxide. Tungsten and molybdenum were sprayed in both wire and powder form, while the oxides and carbides were in powder form. Spraying parameters were established based on density and microstructure. Selected physical properties measured were density, thermal expansion and hardness. Crystallographic studies were made to determine stability of the materials under the ultra-high-temperature spraying conditions. The deposited materials were analyzed for oxygen and nitrogen. Tensile testing of the metals has been conducted at temperatures including 4500° F for tungsten and 3000° F for molybdenum.

Introduction

The significant activity, in the past several years, in the field of plasma formation from an electric arc would lead one to believe that this development is of fairly recent origin. Actually, considerable work was done on plasmas in the first decade of the present century. These early attempts confirmed the theoretical assumptions, but actual operation of plasma-generating equipment was limited to seconds or several minutes before nozzle failure occurred. Following this early work, interest lagged because there was little apparent need for an ultra-high-temperature heat source.

However, within the past few years, the interest in high-temperature technology has increased tremendously. This interest had been stimulated by the severe demand placed on materials for advanced ram-jet, rocket motors and missile applications. To test these materials in the laboratories under conditions simulating actual operation, not only very high-heat fluxes were required but also testing temperatures well above the melting point of all known materials. Consequently, there was a renewed interest in plasma generation and in the development of equipment which would operate for extended periods of time.

This development had been watched with keen interest by those in the metallizing field since the dream of every investigator in this field has been to have a heat source which would melt all known materials and a choice of gases that would not react with the material being deposited. This development has held great promise not only in the field of high-temperature coatings but also in the fabrication of complex shapes.

This paper will describe arc-plasma metallizing equipment for the spraying of wire and powder. The spraying of various metals, carbides and oxides will be covered. Some of the physical and mechanical properties of these materials in both the as-sprayed and heat-treated conditions will be reported.

Equipment

Wire Gun

Basically, plasma-generating equipment is quite simple in design. An electric arc is formed between an electrode in a plenum chamber, through a constricting passage, to another electrode. The plasma-forming gas flows from the plenum chamber through this constricting passage. The confining passage and plasma-forming gas reduce the cross section of the arc, increasing its density and temperature. Energy is transferred from the arc to the gas, forming the plasma.

For spraying wire, the consumable electrode, inert-gas unit shown in Fig. 1 was used. This gun is extremely simple in design and construction. A 0.040-in. wire is introduced into the gun by means of a wire-feed unit incorporating wire-straightening rolls. The wire is directed through the wire guide. A high-frequency arc starter initiates the arc and, under certain conditions of operation, helps maintain the arc. The arc is formed between the wire and the water-cooled nozzle and is stabilized by the flow of high-pressure argon gas.

The gun can be operated using various power sources on either direct or alternating current. High-density deposits have been obtained with the wire charged either anodically or cathodically. Most stable operating conditions were achieved with the wire negative and when a d-c motor generator was used as the power source. The original design operated under the following settings:

Voltage, v	40
Current, amp	200
Wire speed, ipm	40–100
Argon pressure, psi	50–400

Using tungsten wire, a speed of 100 ipm represents a deposition rate of 2.5 kg/hr. The quality of the deposit and the deposition efficiency were better at the higher gas pressures. With the higher pressures, the spray pattern was more confined, a finer spray was produced and the particle velocity was increased. Under these conditions, particle size distribution was as follows:

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Mesh size	%
−100	12.2
−100, +200	27.8
−200, +325	21.7
−325	33.3

It is recognized that apparent particle size, as determined by the water-collection method, may be finer than actual since there is some fragmentation of the molten particles on striking the water.

Modification of the original design has been made which permits operating at higher amperage with a significantly greater wire-feed rate and at relatively low gas pressures. The results of a study conducted with the modified gun are listed in Table 1. These results were obtained with an arc voltage of 40v and the gas pressure at 50 psi. (Current was varied from 290 to 490 amp and the wire-feed rate was varied from 100 to 400 ipm.)

Table 1—Results of Study with Modified Wire Gun

Wire-feed rate, ipm	Kw	Kg/hr	Kg/kw
100	11.6	2.55	0.220
150	14.0	3.82	0.273
200	16.4	5.10	0.311
250	17.6	6.37	0.362
300	18.0	7.65	0.425
350	18.2	8.92	0.490
400	18.8	10.20	0.542
450	19.5	11.73	0.601

The results in Table 1 show a five-fold increase in deposition rate and a three-fold increase in energy transfer efficiency. Figure 2 shows this modified gun in operation.

Powder Gun

The powder gun operates on the nonconsumable-electrode arc principle and a schematic is shown in Fig. 3. The plasma is formed in the throat of the water-cooled nozzle. Approximately $^1/_4$ in. from the end of the nozzle, a hole is provided for the introduction of the powder. The gun is operated from two 600 amp motor generators and is rated at 40 kw.

Whereas the wire gun can only be operated using argon, a number of plasma-forming gases can be used with the powder gun. Reported plasma temperature, enthalpy, energy-transfer efficiency for various gases are listed in Table 2. From Table 2, it would appear that hydrogen would be the best gas to use, not only for its high enthalpy and efficiency of heating, but also for its low cost. However, when hydrogen alone is used as a plasma-forming gas, it has a very erosive effect on the nozzle and greatly reduces nozzle life. For long nozzle life, the percentage of hydrogen must be reduced to 10 volume percent, the balance being nitrogen. This mixture was used in much of the work which will be reported in subsequent sections.

Table 2—Results of Study with Powder Gun

Gas	Power, kw	Calculated plasma, T °F	Enthalpy, Btu/lb	Arc voltage	Efficiency
N_2	60	13,200	17,900	65	60
H_2	62	9,200	138,000	120	80
He	50	36,000	92,000	47	48
A	48	26,000	8,400	40	40

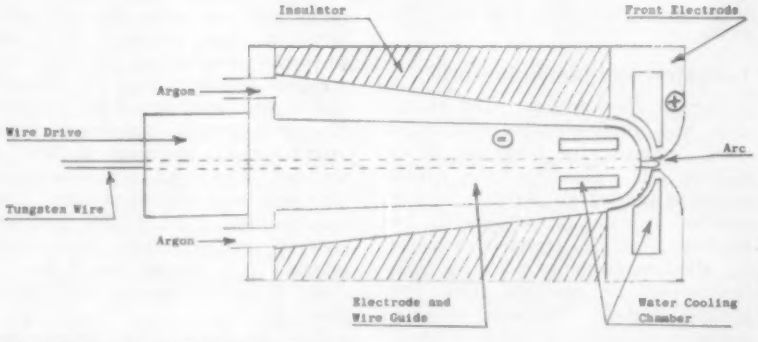

Fig. 1—Schematic of wire arc-spray gun

Fig. 2—Wire arc-spray gun in operation

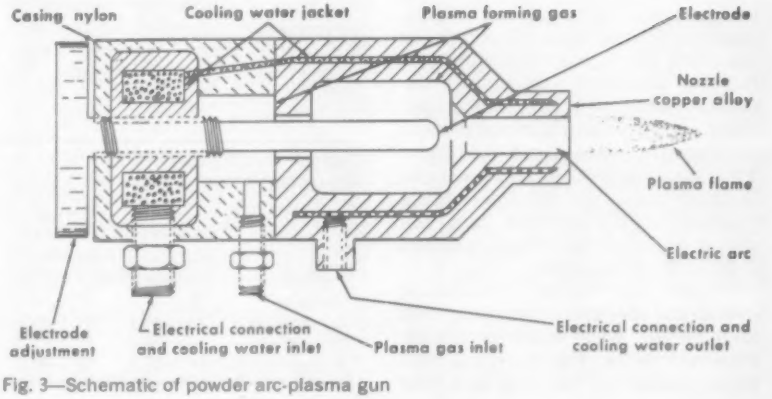

Fig. 3—Schematic of powder arc-plasma gun

Investigation

The over-all objective of this investigation was to determine the mechanical and physical properties of a number of materials with melting points above 4500° F deposited by the plasma-spraying process. These properties included density, hardness, tensile strength, crystallography and thermal expansion. Where applicable, determinations were to be made both in the "as-sprayed" and heat-treated condition. In addition, the oxygen and nitrogen contents were to be determined. Included in the study were tungsten, molybdenum, tantalum carbide, hafnium carbide, cerium oxide, zirconium oxide and hafnium oxide.

Tungsten and Molybdenum

Sample Preparation. The tungsten and molybdenum specimens were prepared by spraying on a 0.75-in. OD aluminum tube which serves as a mandrel. Aluminum was selected because it can readily be leached from the sprayed deposits by alkaline reagents with no contamination or reaction with the sprayed metals. The tube configuration was chosen to allow internal cooling during deposition. The mandrel was chucked in a lathe and rotated to assure a uniform deposit. For the wire-sprayed specimens, 0.040 wire was used. Wire speed was 100 ipm. The powder specimens were prepared under the following conditions:

Power input to gun, kw.....28
Plasma-forming gas.....
.....90 ft³/hr N_2–10 ft³/hr H_2
Particle size, mesh....−200, +325
Gun-to-work distance, in.....2–3
Powder-carrier gas.....10 ft³/hr N_2
Powder-feed rate, lb/hr.....6
Calculated plasma.....
temperature, °F.....9500

The higher power operation of the powder-spraying equipment produced a hotter and longer flame than the wire-spraying equipment. It was necessary to divert the plasma flame from direct impingement on the deposited material to prevent overheating and oxidation. This was done by directing a narrow blast of shop air at the exiting plasma. Blast pressure was adjusted to divert the plasma without deflecting the particles.

Under the above conditions, cylindrical specimens 4 in. long with a 0.300-in. wall were produced. Removal from the mandrel was accomplished by leaching in a cold 50% NaOH solution for approximately 30 min. Longitudinal sections were cut from the cylinders. Some of these sections were set aside for evaluation of the "as-sprayed" material and the balance of the sections were heat treated. The wire-sprayed specimens were heat treated in hydrogen at 3600° F for 1 hr. The powder-sprayed tungsten was heat treated at 4000° F in vacuum for 2 hr. The powder-sprayed molybdenum was heat treated in hydrogen for 2 hr. at 2150° F and in vacuum for 2 hr at 4000° F.

Gas Analysis. Gas determinations for oxygen and nitrogen were made on both the "as-sprayed" and heat-treated materials. Analysis was by the vacuum-fusion technique. The results are shown in Table 3.

These results indicate that, while the nitrogen pickup was relatively low during the spraying operation, there was considerable oxygen pickup even though the wire is sprayed with argon gas. It is realized that some of this pickup may be due to oxidation of the deposited material while the specimen was being prepared. However, this can only be determined if the spraying is done in a tank under an inert atmosphere.

Density. Density determinations were made on both the as-sprayed and heat-treated materials using a water-displacement method. The accuracy of the water-displacement technique was verified by comparison with accurately machined specimens by direct weighing. The

Table 3—Results of Gas Analysis

Material	Condition	Oxygen	Nitrogen
W—wire	As-received	0.001	0.005
W—wire	As-sprayed	0.254	0.011
W—wire	H_2—3600° F/1 hr	0.018	0.0002
W—powder	As-received	0.113	0.0017
W—powder	As-sprayed	0.814	0.024
W—powder	Vac—4000° F/2 hr	0.011	0.0005
Mo—wire	As-received	0.002	0.008
Mo—wire	As-sprayed	0.897	0.038
Mo—wire	H_2—3600° F/1 hr	0.011	0.0005
Mo—powder	As-received	0.052	0.0033
Mo—powder	As-sprayed	1.020	0.103
Mo—powder	Vac—4000° F/2 hr	0.042	0.0001
Mo—powder	H_2—2150° F/2 hr	0.037	0.0013

Table 4—Results of Density Determinations

Material	As-sprayed density, % theoretical	Heat-treated density, % theoretical
W—wire	85.0–87.0	87.0–89.0
W—powder	83.0–84.0	84.5–85.5
Mo—wire	88.0–89.0	90.5–91.5
Mo—powder	86.2–87.1	89.3–90.2

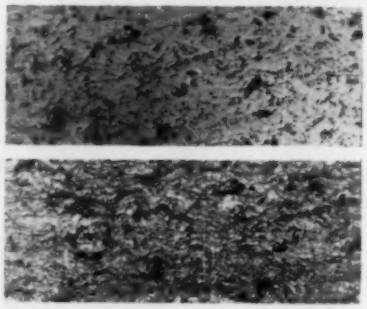

Figure 4—As-sprayed tungsten wire, X 100. (Reduced by 1/3 upon reproduction.) Top: Unetched; bottom: etched

Fig. 5—Electron micrograph of as-sprayed tungsten wire. X 6000. (Reduced by 1/2 upon reroduction.)

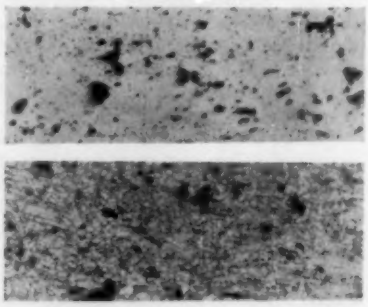

Fig. 6—Sprayed tungsten wire after 1-hr heat treatment at 3600° F in hydrogen. X 100. (Reduced by 1/3 upon reproduction.) Top: Unetched; bottom: etched

as-sprayed densities of the wires were approximately 2% greater than that of the powders. The 3600° F sintering treatment increased the density of the wire-sprayed deposits 2.0–2.5% and the powder-sprayed deposits 1.5–3.0%. Results are listed in Table 4.

Hardness. Hardness values were obtained with a Vicker's hardness tester using a 1 kg load. Hardness readings were taken on specimens that were metallographically mounted and polished (see Table 5).

Table 5—Hardness Values

Material	VHN as-sprayed	Heat treated
Mo—wire	168–183	155–159
Mo—powder	321–368	125–175
W—wire	246–263	238–255
W—powder	330–390	162–200

Annealed wrought molybdenum has a hardness of 165 VHN and annealed wrought tungsten 375 VHN. The lower values obtained on the sprayed material may be due to the porosity of the material.

Microstructure. Photomicrographs of the as-sprayed and heat-treated structures of the wire-sprayed tungsten and molybdenum deposits are shown in Figs. 4, 5, 6 and 7. Figure 4 shows the as-sprayed structure of tungsten in both the unetched and etched condition. The structure is typically lamellar with scattered large voids throughout the structure. Greater detail is revealed in Fig. 5, an electron micrograph. This photomicrograph shows the bonding between the lamellar and the subgrain structure of the individual platelets. A 1-hr. hydrogen heat treatment at 3600° F produces some changes in the structure (see Fig. 6). Considerable recrystallization has taken place but there is still evidence of the original lamellar structure.

Figure 7 shows the microstructure of the as-sprayed molybdenum wire and the structure after the 1-hr hydrogen heat treatment at 3600° F. The as-sprayed structure, top, has fewer large voids than the as-sprayed tungsten (see Fig. 4). The 3600° F heat treatment completely eliminated the lamellar structure through the mechanism of recrystallization and grain growth.

The structures of both the as-sprayed powder tungsten and molybdenum deposits are significantly different than the wire sprayed materials (see Figs. 8, top, and 9, top). The lamellae are smaller and of more uniform size. Voids, also, are considerably smaller and much more uniformly distributed.

The heat-treated structure (see Figs. 8, bottom, and 9, bottom) also show noticeable differences. The recrystallized grain size of the powder-sprayed tungsten is much finer than that of the wire-sprayed tungsten despite a higher heat-treating temperature, 4000° F, and a longer time at temperature, 2 hr. However, these same heat-treating conditions produced a massive grain growth in the powder-sprayed molybdenum deposits (see Fig. 9, bottom).

Table 6—Results of Tensile Tests

Sprayed material	Sintering treatment	Tensile strength, psi 75° F	2000° F	3000° F	3500° F	4500° F
W—wire	H_2—3600° F/1 hr	5,200	10,500	...	...	...
W—powder	Vac—4000° F/2 hr	6,700	15,300	7100	3800	1600
Mo—wire	H_2—3600° F/1 hr	13,700	15,600	...	...	...
Mo—powder	H_2—2150° F/2 hr	...	6,600	2000	...	...
Mo—powder	Vac—4000° F/2 hr	30,500	10,500	...	...	...

Tensile Properties. Tensile properties were determined only on the heat-treated materials since the as-sprayed deposits were too brittle to be machined into tensile specimens. A button-head type tensile specimen was used having a 1-in. gage length and a 0.160-in. diam. Even the heat-treated specimens needed special precaution in machining. Very light feeds were required to prevent breakage.

Tensile tests were run at room temperature and elevated temperatures (see Tables 6 and 7). The elevated-temperature tests were conducted in an evacuated capsule at an absolute pressure of 1×10^{-4} mm of mercury. A head travel rate of 0.01 ipm was maintained during testing.

All specimens tested failed in a brittle manner with the exception of those listed in Table 7.

It is significant to note that the 2000° F strength of the molybdenum wire-sprayed samples was 50%

Table 7—Yield, Elongation and Reduction of Area Data

Sprayed material	Sintering treatment	Test temperature, ° F	2% yield strength	Elong., %	Reduction of area, %
W—powder	Vac—4000° F/2 hr	4500	1500	30.0	16.6
W—powder	Vac—4000° F/2 hr	3500	3300	9.7	7.6
W—powder	Vac—4000° F/2 hr	3000	5600	8.0	7.5
Mo—powder	Vac—4000° F/2 hr	2000	5300	23.0	24.0
Mo—powder	H_2—2150° F/2 hr	3000	1700	2.0	2.0

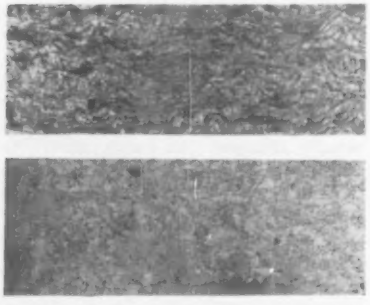

Fig. 7—Sprayed molybdenum wire. X 100. (Reduced by 1/2 upon reproduction.) Top: As-sprayed, etched; bottom: 3600° F heat treatment for 1 hr in H_2, etched

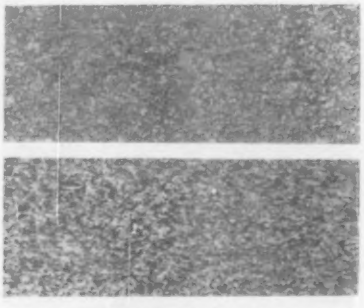

Fig. 8—Sprayed tungsten powder. X 100. (Reduced by 1/2 upon reproduction.) Top: 4000° F heat treatment for 1 hr in vacuum; bottom: as-sprayed, etched

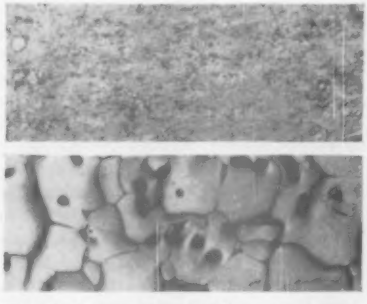

Fig. 9—Sprayed molybdenum powder. X 100. (Reduced by 1/2 upon reproduction.) Top: As-sprayed, etched; bottom: 4000° F heat treatment for 1 hr in vacuum

higher than the powder-sprayed sample but that the former had no ductility. Apparently, the high sintering temperature and longer heat-treating time are needed to impart ductility to the material. The effects of high sintering temperature and longer sintering are more pronounced on room-temperature strength, where the 4000° F sinter for 2 hr yielded a 30,500 psi strength compared with 13,700 psi after 1 hr heat treatment at 3600° F. However, this may be due, in part, to differences in the as-sprayed structure since the former was powder sprayed and the latter wire sprayed.

Crystallographic Structure. X-ray diffraction studies showed the lattice parameter of the wire-sprayed tungsten to be $a_0 = 3.1648A°$, which is identical with the ASTM accepted value for tungsten. The diffraction lines were broader than are commonly found, and the resolution of the Co $K\alpha_1$ and Co $K\alpha_2$ did not appear. This lack of resolution may be due to the presence of microstrains since the material was in the as-sprayed condition. The powder-sprayed tungsten showed a slightly larger value, $a_0 = 3.1656A°$. The lattice parameter of the heat-treated wire sprayed molybdenum was $a_0 = 3.1534A°$ which is slightly larger than the accepted value of 3.1472A°.

Thermal Expansion. Thermal expansion measurements were made on 0.190-in. diam bars 2.5-in. long from room temperature to 2100° F. Expansion was measured using a commercial dilatometer and the results are shown in Fig. 10.

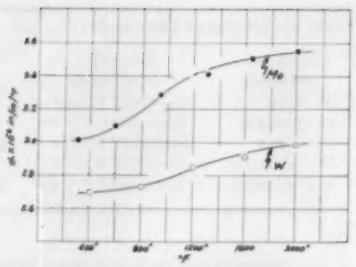

Fig. 10—Thermal coefficient of expansion curves for sprayed molybdenum and tungsten

Carbides

The carbides selected for investigation were hafnium carbide, mp 7030° F, and tantalum carbide, mp 7010° F. The initial specimens were sprayed with the powder gun under the same spraying parameters used for spraying tungsten and molybdenum with a 90% N_2 – 10% H_2 mixture as the plasma-forming gases. The microstructure of the deposited hafnium carbide is shown in Fig. 11. Examination of the microstructure shows the presence of more than one phase, indicating that some transformation of the hafnium carbide has occurred during the spraying operation. A similar condition was observed with the sprayed tantalum carbide. Before proceeding with any properties evaluation, it was necessary to determine the nature of the transformation that had taken place.

X-ray diffraction patterns of the "as-received" hafnium carbide and tantalum-carbide powders were studied first to establish their purity. In each case, the patterns showed only the lines for hafnium carbide and tantalum carbide, respectively. No other compounds or phases were detected.

The X-ray diffraction patterns produced by the sprayed materials were poor in quality due to microstrains and distortions in the lattices. By heat treating the deposits at 2000° F in vacuum, resolution was improved and Hf(C,N), HfO_2 and Hf were detected in deposits from the HfC powder and Ta_2C and Ta in the deposits for TaC powder. In the latter case, no TaC was found in the deposit. From these results, it is apparent that there is some dissociation of the HfC and TaC at the high-plasma temperature.

This was confirmed by chemical analysis of the deposited materials (see Table 8).

Table 8—Chemical Analysis of Deposited Materials

Material	Chemical Analysis, % Metal	Carbon	Nitrogen	Oxygen
Hafnium carbide	94.1	2.92	0.858	1.88
Tantalum carbide	93.0	1.12	0.326	1.96

Fig. 11—As-sprayed hafnium-carbide powder

Table 9—Results of X-ray Diffraction Studies on Oxides

Oxide	System	Lattice a_0 measured	Lattice a_0, ASTM
CeO	FCC	5.411A°	5.411A°
ZrO_2	Cubic (stabilized)	5.123A°	5.07A°

The stoichiometric composition of HfC is 93.6% Hf and 6.31% C, and that of TaC, 93,77% Ta and 6.23% C. Apparently, there is a considerable loss of carbon during the spraying operation due to dissociation. The decomposition of the TaC proceeded to a much greater extent in that less than 20% of the original carbon had been retained. The high-nitrogen content (0.858%) of the deposited HfC confirms the presence of the complex Hf (C, N) since the maximum retained nitrogen in the tungsten and molybdenum deposits was 0.103%. The 0.376% nitrogen present in the deposits from TaC powder would indicate that some TaN may be formed. The high-oxygen contents in both deposits, 1.88 and 1.96%, are strong evidence for HfO_2 and TaO_2 being present.

Since it was demonstrated that the nitride was being formed using nitrogen as the plasma-forming gas, subsequent spraying was conducted with an argon–hydrogen mixture to form the plasma. The patterns of these deposited materials were appreciably different. The sprayed HfC powder showed a major amount of HfC and minor amounts of HfO_2. The deposit from the TaC powder showed primarily TaC with some Ta_2C. However, the resolution was rather poor, and since some of the lines of Ta and TaC are fairly close, Ta may have been present but not detected. Considerably more work is to be done in this area before fully accurate data are available.

Oxides

Work on the oxides has been started only recently and the results to date are rather fragmentary. X-ray diffraction studies of the sprayed deposits have been made on two oxides, CeO, ZrO_2, with the results shown in Table 9. The higher reading for ZrO_2 is due to the 5% addition of CaO for stabilizing purposes.

Hardness and density determinations also have been made (see Table 10).

Discussion

It has been demonstrated that the highest-melting-point materi-

Table 10—Hardness and Density Determinations on Oxides

Oxide	VHN	Density, gm/cc	Theoretical, %
CeO_2	168–205	6.58	92.3
ZrO_2	636–805	5.14	92.4
HfO_2	251–313	8.39	86.8

als can be sprayed successfully with the arc-plasma equipment. For the spraying of tungsten and molybdenum, the powder method appears to be more advantageous. The powder deposits have a much more uniform as-sprayed structure and a finer sintered structure than the wire-sprayed material. Although the wire-sprayed deposits are more dense in the as-sprayed condition, no beneficial effects are apparent in subsequent heat treatment. In addition, the price of tungsten and molybdenum powders is approximately one-fifth the price of the metals in wire form.

Wire spraying has definite advantages in that deposition rates are significantly higher and that the power requirements are considerably lower. Furthermore, the equipment requirements are relatively inexpensive compared with the powder-gun equipment.

Appreciable amounts of nitrogen and oxygen were retained in the deposits during the spraying operation. The nitrogen-plasma forming gas was probably the major source of the retained nitrogen though some nitrogen was aspirated from the surrounding air. The high-oxygen contents were due primarily to oxidation of the specimen during spraying and secondarily to oxygen aspirated into the plasma stream. To determine more accurately the sources of oxygen and nitrogen, it would be necessary to do the spraying in a controlled-atmosphere tank. Future experiments are planned under controlled-atmospheric conditions.

The property data obtained to date are still of a preliminary nature. Many additional tests are planned including; (1) deposition studies under controlled-environment conditions, (2) compressive modulus and transverse rupture testing, (3) specific heat and (4) resistance to thermal shock.

Acknowledgment

The gun used for spraying wire was developed by Henry Libby of Small Aircraft Engine Department, Lynn, Mass. The powder gun was obtained from Thermal Dynamics Corp., Lebanon, N. H.

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RESEARCH NEWS

Welding Aluminum-Copper Alloys

"A study of the Post-Weld Thermal Treatment of an Aluminum-Copper Alloy," R. P. Neuman and E. C. Roberts—*The Trend in Engineering*, Univ. of Washington, Oct. 1960, pp. 18–21, 30.

With proper control equipment, weldments can be produced, in aluminum-copper alloys, that exhibit joint efficiencies of 100%. However welding is only part of the practical problem. To attain the equally important objective of providing a mechanically and chemically desirable weld structure, post-weld thermal treatments are required. Tests were conducted and the results indicate the need for careful planning to avoid the formation of concomitant zones of both brittle and ductile components. Work is now under way on a quantitative study of these zones so that brittle failure can be predicted on the basis of microstructural data.

Brittle Fracture Study

"The Brittle Fracture Problem and the Load Carrying Capacity of Structures," L E. Benson and S. J. Watson. Reprint of an 8-page article from *Metallurgia*, April 1960, is available from Associated Electrical Industries (Manchester) Ltd., Trafford Park, Manchester 17, England.

The problem of brittle fracture in steel is considered in relation to strength. The authors are concerned with problems resulting not from welding alone but from more general causes.

The results of published work supported by a series of notch tensile tests, are discussed with a view toward establishing several points: (1) An exposure of some popularly held fallacies; (2) The importance of the size of the part and the size and geometry of the stress concentrating features; (3) The need for providing design engineers with more useful data in terms of stress and strain rather than energy of fracture of transition temperature.

It is shown that brittleness does not necessarily imply lack of strength or inadequate ductility. The ability to resist brittle fracture is not a simple function of some inherent property of the material but depends on imposed conditions. The authors confirm the view that no standardized test has significance for the engineer except in relation to these conditions.

Electrode for Spatter-Free Welding of Steel in Carbon Dioxide

Spatter-free metal transfer is only one of the advantages of adding Na, K or Rb to cesium wire coatings in the CO_2-shielded metal-arc welding of mild steel

BY EVERETT CUSHMAN

ABSTRACT. A welding wire has been developed for carbon-dioxide-shielded metal-arc welding of mild steel without weld spatter. The new wire also makes unnecessary the rigid control of arc length formerly required for carbon-dioxide-shielded arc welding.

The wire is treated with a dilute solution of two alkali-metal compounds. The treatment produces a coating that is extremely thin and does not interfere with electrical contact between the wire and the contact tube of the welding equipment. Conventional, commercially-available equipment for gas-shielded metal-arc welding is used, without modification, with the new wire.

The resulting arc for straight-polarity direct-current operation is similar in appearance and performance to the spatter-free spray-transfer arc which is characteristic of argon-shielded arc welding with reverse-polarity direct current. The wire composition is adjusted so that sound weld metal can be deposited with long arc lengths. The use of a long arc overcomes the undesirably high, narrow weld reinforcement which often results when using the buried-arc techniques of conventional carbon - dioxide - shielded arc welding.

Introduction

Inert-gas-shielded metal-arc welding is particularly suited for the joining of reactive metals such as aluminum. Chemical reaction of the air and metal is prevented without having to provide a flux that can leave harmful residues or inclusions after welding. Furthermore, the arc is stable and tends to remain constant in length. There is no weld spatter, and the welds are sound and free from slag. The use of the inert-gas process is justified by its great superiority over the older methods of joining reactive metals.

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The process can be used for the fabrication of mild steel, but this metal also can be welded readily by other well-established methods. Although the inert-gas process has several technical advantages over older methods, these advantages often are offset by economic disadvantages. To reduce the cost of gas-shielded arc welding, carbon dioxide was introduced as a shield to weld mild steel. This somewhat oxidizing atmosphere does not have an adverse effect on weld quality; and nitrides, which are harmful, are not formed because the weld is shielded from the air. Unfortunately, the advantage of lower cost is cancelled to a considerable degree by weld spatter which clogs gas passages and necessitates cleaning of the work and equipment.

Weld spatter has a number of causes. Large molten drops often bridge the space between the welding wire and work. Acting as fuses conducting high short-circuit current, they disintegrate into a number of small drops which are expelled from the joint. Molten drops forming on the tip of the wire are often pushed sideways by arc forces so that they do not enter the weld. Spatter can be minimized by keeping the arc length sufficiently short (i.e., buried) to trap the drops in the arc crater. The need to limit arc length within a narrow range makes control of the arc more difficult than when argon shielding is used. Furthermore, the use of short arc lengths results in undersirably high and narrow weld reinforcement.

When argon is used for shielding, the arc usually is operated with reverse-polarity direct current (electrode positive). Above a critical current level, molten metal is transferred axially through the arc to the work in a rapid succession of minute drops. This type of metal transfer in the arc is called "spray transfer." As the welding current is dropped below the critical value, the mode of metal transfer changes abruptly; the molten drop size increases to a diameter larger than that of the wire, and the number of drops transferred per second decreases. This type of transfer is called "drop transfer." The current at which the transition from spray to drop transfer occurs is defined as the "transition current."

When welding in argon with straight-polarity direct current (electrode negative) and an uncoated electrode, large molten drops are formed. These drops are not transferred axially. Instead they are ejected in random directions from the wire tip. The arc is unstable and weld spatter is produced at all current levels. Previous investigators have shown that argon-shielded, straight-polarity direct-current arcs can be made to produce spray transfer by activating the electrode with various emissive agents. Such a treatment causes a reduction in both the cathode voltage drop and the heat generated at the wire tip. Activated wires, therefore, have lower melting rates with straight-polarity direct current than untreated bare wires under otherwise identical conditions.

When carbon dioxide is used with an untreated bare steel electrode, weld spatter is produced whether the electrode is negative or positive. The object of the investigation described in this paper was to develop a spatter free method of welding in a carbon dioxide shielding atmosphere utilizing an "open" arc. Since it was known that metal transfer characteristics could be modified in the straight-polarity argon arc by activating the cathode, a similar approach was used for investigating the CO_2-shielded arc.

The successful conclusion of the investigation described in this paper is the subject of U. S. Patent No. 2,932,722, issued Apr. 12, 1960.

Results: Single-component Coatings

Effect of Emissive Agents on Melting Rate

Whenever a wire-activating compound has produced spray transfer, it always has caused a reduction in the melting rate of the electrode. Consequently, when testing the effects of coating wire with activation compounds in a carbon dioxide shield, reduction in melting rate of the electrode (which is easily measured) was used as an indication of the compound's ability to act as an emissive agent in this atmosphere and as a clue to the possibility that a particular compound might be useful as an agent to produce spray transfer. Ordinarily the amount of emissive agent required to have a strong effect on arc action is so small that the coating on the wire is invisible; less than 1 mg of a cesium compound distributed over the surface of 1 ft of wire cuts the melting rate in half. Such small quantities are difficult to measure by ordinary means. Consequently, reduction in melting rate was also used as experimental evidence that an effective quantity of material had, in fact, been applied to the wire.

Emissive agents, which produce spray transfer in an argon shield, are compounds of metals selected from the group consisting of the alkali metals, the alkaline-earth metals, and the rare-earth metals. Compounds of many of these metals were coated on sample wires which then were tested in both argon and carbon dioxide shields, using straight-polarity direct current. The quantity of compound applied to the wire surface was varied from trace amounts, having slight effect on melting rate, up to coatings sufficiently thick to interfere with electrical contact between the wire and the contact tube in the welding equipment.

Melting Rate of Coated Wire in Argon

Table 1 compares the melting rates in argon of a bare wire and wires coated with representative alkali-metal, alkaline-earth-metal and rare-earth-metal compounds. The arcs were operated with straight-polarity direct current. The electrode was a $^1/_{16}$-in. diam steel wire containing 0.1% C, 1.0% Mn and 0.4% Si. Each of the coated wires produced spray transfer; the bare wire did not. Note that the melting rates of the coated wires were much lower than the melting rate of the uncoated wire.

Effects of Alkaline-earth and Rare-earth Compounds in Carbon Dioxide

None of the compounds selected from the alkaline-earth and rare-earth groups was successful in producing spray transfer in carbon dioxide. The data of Table 2 are typical of the results which are obtained when wires are coated with sufficient quantities of these types to produce a considerable reduction in melting rate. The fact that these compounds caused reductions in melting rate is an indication that they still functioned as emissive agents after being changed chemically by reaction with the dissociated carbon dioxide. However, spray transfer evidently can be achieved only if the coating material has some quality in addition to its ability to reduce melting rate.

Effects of Alkali-metal Compounds in Carbon Dioxide

In argon, rubidium and cesium are the most effective alkali metals for producing spray transfer. Their effectiveness is equivalent, and only a minute amount of either metal (on the order of 0.005% by weight of the wire) is required to produce the desired result. When carbon dioxide is used for shielding, the rubidium compounds are not as effective as cesium compounds for reducing the melting rate or producing spray transfer. When relatively heavy coatings of rubidium compounds were applied to sample wires, the melting rate was reduced to a value comparable to that obtained with wires lightly coated with cesium compounds. However, arc action was erratic and the metal was transferred in a mixture of large and small drops with considerable spatter. The carbon dioxide seems to act in some way to prevent the strong emissive-agent effects that might be expected with rubidium compounds.

Of all the coating materials tested, only the cesium compounds showed promise for achieving spray transfer in carbon dioxide. Consequently, a more detailed investigation of the effects of cesium coatings was undertaken to determine the best combination of wire coating and composition.

Effects of Wire Composition

Deoxidizers such as silicon inhibited the action of cesium-compound coatings. Wires of very low silicon content required only a small

Table 1—Effect of Coating on Melting Rate of Welding Wire in Argon

$^1/_{16}$-in. diam wires, straight-polarity direct current

Coating	Arc voltage, v	Type of transfer	Melting rate at 400 amp, ipm
None	32	Drop	400
CsOH	21	Spray	190
$SrBr_2$	22	Spray	215
$La(No_3)_3$	27	Spray	280

Table 2—Typical Operating Data for Welding Wires Coated with Alkaline-earth or Rare-earth Compounds

$^1/_{16}$-in. diam wires, straight-polarity direct current, CO_2 shield

Coating	Arc voltage, v	Melting rate at 400 amp, ipm
None	46	410
$CaCl_2$	37	280
$SrBr_2$	42	255
$Sr(OH)_2$	42	235
$SrCl_2$	42	220
$BaCl_2$	38	200
$La(NO_3)_3$	43	250
CeO_2	39	220

Table 3—Effect of Cesium Hydroxide Coating on Performance of a Low-Silicon Steel Wire

$^1/_{16}$-in. diam wires, straight-polarity direct current, CO_2 shield

Wt % of Cs on wire	Arc voltage, v	Melting rate at 400 amp, ipm	Type of transfer
0	45	400	Drop
0.0018	41	280	Drop
0.0021	42	220	Occasional spray
0.0024	38	190	Spray
0.0028	36	180	Spray
0.0065	37	185	Spray
0.0086	36	180	Erratic spray

Table 4—Effect of Cesium Phosphate Coating on Performance of a Medium-silicon Steel Wire

$^1/_{16}$-in. diam wires, straight-polarity direct current, CO_2 shield

Wt % of Cs on wire	Arc voltage, v	Melting rate at 400 amp, ipm	Type of transfer
0.0030	40	235	Occasional spray
0.0039	38	208	Spray
0.0059	35	200	Spray
0.0089	36	200	Spray
0.0128	35	200	Erratic spray

amount of cesium to cause a large decrease in melting rate and to produce spray transfer at low transition currents, but welds made with these wires were extremely porous due to the lack of sufficient deoxidizer for the molten weld metal. The data given in Table 3 are typical of the results obtained with wires that are low in silicon, aluminum or other deoxidizing metals. This particular sample of $^1/_{16}$-in. diam wire contained 0.12% C, 0.51% Mn, less than 0.02% Si, and less than 0.01% Al. The amount of cesium on the wire was determined by flame photometer equipment, which is particularly well suited to quantitative analyses of alkali metals. During this series of tests, transition currents as low as 205 amp were reached.

Wires containing more silicon than the wire used to obtain the data in Table 3 required larger amounts of cesium to obtain approximately the same reduction in melting rate shown in the table, and the transition currents for the wires with greater silicon content were higher. Table 4 lists the results obtained with various quantities of cesium phosphate coated on a $^1/_{16}$-in. diam steel wire containing 0.12% C, 0.80% Mn and 0.44% Si. The lowest transition current in this series of tests was 360 amp.

Electrodes of this type produced sound welds on semikilled plate when short arc lengths were used, but the weld beads were as high and narrow as those produced with the conventional reverse-polarity process. The weld contour was improved with spray transfer and longer arc lengths, but the welds became porous. Long arc lengths allow the molten metal in transfer to be exposed to the oxidizing action of the dissociated carbon dioxide for a longer time and silicon and manganese, having been oxidized within the arc stream are not available in sufficient quantity to kill the weld metal.

In attempts to improve weld-metal soundness, the silicon or aluminum content of the wires was increased. Cesium coatings caused the melting rates to be reduced but did not develop spray transfer. Other wires were prepared having varying amounts of silicon plus other deoxidizers such as titanium and zirconium in the hope that metals other than silicon or aluminum would not impair the spray-producing potential of the coating. However, increasing amounts of any of the deoxidizers caused increasingly higher transition currents.

Effect of Changes in Geometry

In the course of the investigation, the effect of factors other than wire composition and coating upon the mode of metal transfer became evident. Therefore, a study was made of the effects of variations in arc length, stick-out (the length of wire from the contact tube to the arc end of the wire), and wire diameter. All of the wires were made from the same heat of steel (0.43 Si). Three wire diameters, three arc lengths and three stick-outs were investigated. The wires were coated with a cesium compound in four steps, ranging from 0.005 to 0.015 weight percent of cesium on the wire.

During these tests, consistent results were difficult to obtain. Significant differences in performance were observed even when operating under supposedly identical conditions. Evidently, some unrecognized variable had a strong influence on the arc. Therefore, these data are of dubious value in measuring the effect of the variables being studied. Qualitatively, however, best results were obtained with short stick-outs, short arc lengths and relatively large amounts of cesium on the wire. Reduction of the wire diameter lowered the transition currents. However, extremely short stick-outs had to be used with small diameter wires to obtain spray transfer.

Inconsistency of Results

Differences in performance were noted not only with different wires of the same nominal analysis but also with different sections of wire taken from the same spool. Small diameter wires were particularly troublesome; large differences in transition currents were observed when the same wire was tested on different days. Occasionally there were large differences in soundness of the weld metal deposited by wire from the same spool.

Evidently the full requirements of a commercially-acceptable welding process could not be met by coating the welding wire with cesium compounds alone. However, the test results were sufficiently encouraging to warrant additional research efforts.

Results: Two-component Coatings

Mixtures of Emissive Agents

A study of slow motion pictures of the arcs to treated electrodes, and of synchronized oscillograms of current and voltage, revealed many interesting phenomena. When operating in carbon dioxide with straight-polarity direct current, wires coated with a cesium compound often exhibited periods of erratic behavior during which there were spasmodic changes from spray transfer to the formation of large drops and spatter. During periods of spray transfer the arc appeared to emanate from a conical or hemispherical area around the tip of the wire, and molten metal was ejected in a thin high-velocity jet from the center of the tip. When the arc reverted to spatter and large-drop transfer, the cathode spot appeared to wander about on the bottom of a molten drop forming on the wire tip and to exert an upward force on the drop. A change in location of the arc from the sides of the wire tip to the bottom was accompanied by a simultaneous increase in arc voltage, even though the apparent arc length decreased. These changes in voltage were thought to be due to fluctuations in the cathode voltage drop which, in turn, were caused by changing concentrations of emissive agent on the active area of the cathode. Therefore, a method was sought to make the coating spread more uniformly over the cathode surface. This improvement was believed to be obtainable by changing the physical properties of the coating (such as melting point, viscosity, surface tension) through admixture of a cesium compound with some other material.

An hypothesis was postulated and stated that the wire coating produces spray transfer by preventing the welding current from concentrating in a small spot on the bottom of the electrode. If the hypothesis were true, spray transfer might be accomplished by modifying the emissive material so that it evaporated just before reaching the extreme tip of the electrode. The most likely current path with a material of this type would be through an annular area around the tip of the wire rather than through the extreme tip. The annular area would be favored because it would consist of thermionic material; current through it would require only a low cathode voltage drop whereas the extreme tip would require the high cathode voltage drop characteristic of bare wire. Cesium and its compounds have boiling points or dissociation temperatures which are so low (less than the melting point of steel) that the occasional evident lack of spray-producing effect of the coating was believed due to evaporation of the cesium compound before it reached the annular area. Therefore, an additive that would raise the boiling point of the

Table 5—Coating Mixtures Without Cesium Which Were Tested for Effect on Metal Transfer

Type of mixture	Metals in mixture
2 alkali metals	Rubidium-sodium
	Rubidium-potassium
	Rubidium-lithium
1 Alkali metal and 1 alkaline-earth metal	Sodium-calcium
	Sodium-strontium
	Potassium-strontium
1 alkaline-earth metal and 1 rare-earth metal	Potassium-lanthanum
2 alkaline-earth metals	Barium-strontium
2 rare-earth metals	Lanthanum-cerium

coating was expected to be beneficial. Such systems are used commercially in other applications.

An example of a synergistic effect of two compounds in an emissive agent coating is seen in the electronic vacuum tube. A mixture of the oxides of barium and strontium in such a tube is more effective as a cathode coating than is either of the oxides when used singly. By analogy, some combination of emissive agents on the welding wire was expected to improve its performance.

With the above considerations in mind, tests were made with mixtures of compounds of the following types:

1. Two alkali metals.
2. An alkali metal and an alkaline-earth metal.
3. An alkali metal and a rare-earth metal.
4. Two alkaline-earth metals.
5. Two rare-earth metals.

Of these, a mixture of compounds of cesium and another alkali metal, in proper proportion, produced a remarkable improvement in performance. No other combination of all the coating materials tested was successful.

Table 6—Transition Currents Obtained with Various Molar Ratios of Cesium Compound to Other Alkali-metal Compounds

$^1/_{16}$-in. diam steel wire with moderate silicon content, in CO_2

Mixture	Transition current, amp 0.5 ratio[a]	1.0 ratio	1.5 ratio
$Cs_2CO_3 + Na_2CO_3$	325	295	305
$Cs_2CO_3 + Rb_2CO_3$	320	305	325
$Cs_2CO_3 + K_2CO_3$	330	315	350
CsOH + NaOH	330	305	310
CsOH + KOH	325	300	345
CsCl + NaCl	350	340	370

[a] Molar Ratio = molecules of added compound/molecules of cesium compound.

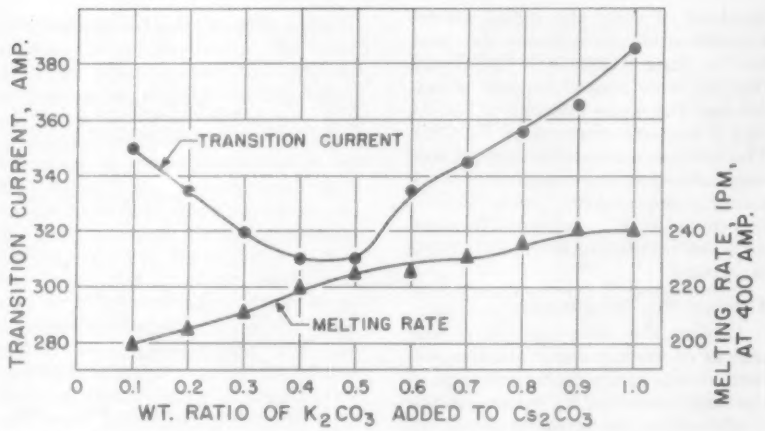

Fig. 1—Effect of adding K_2CO_3 to fixed amount of Cs_2CO_3 on wire surface

Mixtures Not Containing Cesium

Tests of mixtures not containing cesium are described as a group because of the similarity of performance. In this series of tests, both the amount of coating and the proportion of the constituents were varied. None of the coating formulations showed any promise of producing spray transfer. In the interest of brevity, Table 5 lists only the classes of compounds that were tested.

Many of the mixtures tested caused a substantial reduction in melting rate of the electrode, indicating that the material on the wire functioned as an emissive agent after reactions with the carbon dioxide. However, the mechanism for producing spray transfer was absent.

Harmful Additions to Cesium Compounds

Attempts to improve the performance of cesium coatings on wires containing a moderate amount of deoxidizers by the addition of alkaline-earth or rare-earth compounds were unsuccessful. Compounds of calcium, strontium, barium, lanthanum and cerium had a harmful effect on the activity of the cesium coating. The melting rate of the electrode was not appreciably affected when these compounds were combined with cesium. However, each of them caused a deterioration from spray transfer to spatter.

Helpful Additions to Cesium Compounds

Good results were obtained when alkali-metal compounds were added to cesium-compound coatings. The effects were most pronounced when the weight of the added compounds in the mixture was less than that of the cesium compound. Figure 1 shows the effects on transition current and melting rate when gradually increasing amounts of potassium carbonate were added to a fixed amount of cesium carbonate on the wire surface (approximately $^1/_2$ mg per ft of wire). A decided dip is found in transition current with K_2CO_3/Cs_2CO_3 weight ratios between 0.4 and 0.5. Significantly, the ratio of the molecular weights of these compounds also falls between these values:

$$\frac{\text{mol. wt. of } K_2CO_3}{\text{mol. wt. of } Cs_2CO_3} = \frac{138.2}{325.8} = 0.42$$

An equal number of molecules of the compounds on the wire surface produced the minimum transition current in this particular test.

Coatings of other cesium and alkali-metal compounds having various weight ratios were tested to determine whether equal molar ratios of the effective compounds also produced minimum transition currents. Each test wire was coated with a fixed weight concentration of a cesium compound and either 0.5, 1 or 1.5 times the molar equivalent of the other compound. The results of these tests are listed in Table 6. With each mixture of compounds, the lowest transition current was obtained when the compounds were present in equal molar ratios.

In each of the equal-molar-ratio mixtures discussed thus far, the anions were the same and equal numbers of the metal atoms were present. For instance, in mixtures of the carbonates, two metal atoms are present in each molecule; while mixtures of the hydroxides contain one metal atom per molecule. To determine whether equal numbers of the complete molecules or equal

numbers of only the metal atoms was essential to achieve the best results, three mixtures of CsOH and Na_2CO_3 were coated on test wires. All had the same amount of CsOH and a variable amount of Na_2CO_3. The minimum transition current was obtained when the compounds were mixed in the ratio of $^1/_2$ mole Na_2CO_3 to 1 mole CsOH. In such a mixture an equal number of the metal atoms is present.

Effects of Wire Composition

During the investigation of the effects of adding other alkali-metal compounds to the cesium compound coatings, the welding wires usually contained a moderate amount of deoxidizers. The nominal analysis of the wires was: 0.1% C, 1% Mn and 0.4% Si. Although the dual mixtures improved the arc stability and the ability to weld at currents lower than previously possible, welds were usually porous unless short arc lengths were maintained. Therefore, concurrently with the emissive agent study, a separate project was in progress to develop wire which would produce sound weld metal with long arcs in a shield of carbon dioxide.

Of all the experimental wires tested to date, one containing approximately twice as much manganese and silicon as the moderately deoxidized electrodes has given the best results with carbon-dioxide-shielded spray-transfer arc welding. This wire contains sufficient deoxidizer to produce sound welds with arcs as long as $^1/_8$ in. (measured from the plane of the work surface to the wire tip). Contrary to the experience with cesium treatments alone, the two-component coatings are effective in producing stable spray transfer and low transition currents with the highly deoxidized electrodes. Furthermore, small-diameter wires of this composition, when properly coated, are found to produce spray transfer without having to resort to short stick-outs.

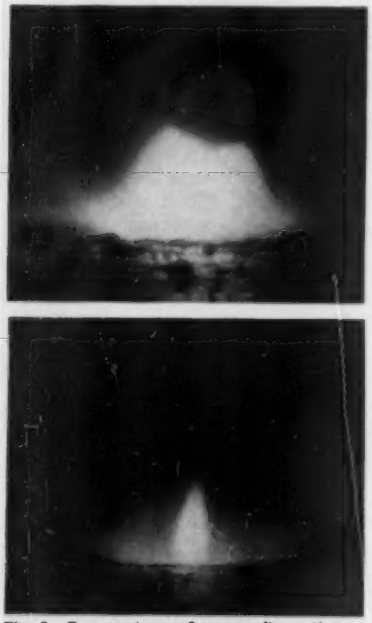

Fig. 2—Comparison of arc configurations with bare and coated wire in CO_2 (upper view—reverse-polarity direct-current arc with bare wire; lower view—straight-polarity direct-current arc with coated wire)

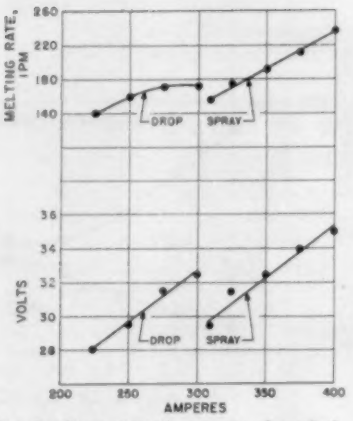

Fig. 3—Characteristic curves of coated electrode operating above and below transition current in CO_2 shield

The highly deoxidized wire requires a heavier coating of emissive agents to obtain minimum transition current than do the wires of moderate deoxidizer content. Flame photometer analyses of properly coated, highly deoxidized wires show that they contain slightly more than 0.02% by weight of cesium plus an appropriate amount of whichever other alkali metal was added to the coating.

Transition currents with three different wire diameters were as follows: 0.063 in. diam, 300 amp; 0.054 in. diam, 250 amp; and 0.045 in. diam, 200 amp.

The smaller diameter wires are useful when welding relatively thin sections, since joints can be made with spray transfer at the lower energy level required for the thin sections.

The photographs of Fig. 2 illustrate the differences in arc configuration and metal transfer when welding in carbon dioxide with reverse-polarity direct current and a bare wire, and when welding with straight-polarity direct current and a highly deoxidized wire which was coated with a mixture of cesium and potassium carbonates. In each case, the wire diameter was 0.045 in., the arc length was $^1/_8$ in. and the current was 225 amp. The photograph of the reverse-polarity arc shows the electrode wire silhouetted against a drop of molten metal an instant before the drop was detached from the wire. The arc forces on the drop are in opposition to the force of gravity, preventing axial transfer to the work and producing spatter. The photograph of the straight-polarity arc, using a coated wire, shows the pointed tip of the wire and zones of different luminosity in the arc plasma. Slow motion pictures of this arc show that all of the molten metal is transferred as small drops through the center of the highly luminous core of the arc. Their velocity is so high that their motion could not be stopped in a still photograph.

Arc Characteristic Curves

The change in metal transfer at transition current with carbon dioxide shielding and straight-polarity direct current is much more abrupt than the one observed with argon shielding and reverse-polarity direct current. With the change in transfer, a simultaneous change can be detected in the electrical properties of the arc. Tests show that, in carbon dioxide, the volt-ampere characteristic curve of an arc from an emissive coated wire is discontinuous at the transition current.

In testing a $^1/_{16}$-in. diam wire coated with a mixture of cesium and sodium carbonates, spray transfer was established initially at a current level well above the transition current. The current and wire feed were then decreased simultaneously to maintain a constant arc length. The voltage decreased linearly with current until the transition current was reached. Here an abrupt increase in both voltage and wire melting rate was necessary to maintain a given arc length. This relationship is illustrated by the curves in Fig. 3. They seem to indicate that the effectiveness of the emissive agents decreases suddenly as the current drops below its transition level.

In all of the tests described thus far, the power supply was a motor driven generator with a drooping volt-ampere characteristic. Although a complete evaluation of other types of power supplies has not been made, preliminary tests indicate that transition currents are higher when a constant-potential generator is used. The difference in transition current may be due to the discontinuity of the arc characteristic curve.

For a particular set of welding

conditions (arc length, stick-out, type and diameter of wire), the arc characteristic curve is independent of the type of power supply used. However, the characteristic curve of the generator can be changed by adjusting the generator controls. A stable arc can be maintained only at the current and voltage obtained at a point of intersection of the arc characteristic curve and the power supply characteristic curve. Figure 4 shows an arc characteristic curve on which are superimposed the characteristic curves of a drooping-voltage generator and a constant-potential generator when the machine controls were at the particular settings at which a transition from spray to drop transfer occurred. The characteristic curve of each generator intersects both the spray-transfer and drop-transfer portions of the arc characteristic curve. However, the intersections with the spray-transfer portion are at different current values. In this test the transition currents were: 350 amp when using the constant-potential generator, and 310 amp when using the drooping-voltage generator.

Discussion

Spray transfer seems to be impossible when the path of welding current through the tip of the electrode is confined to a small high-current-density area of the molten surface. As postulated earlier, such a localized concentration of current would be prevented through the use of an emissive agent which evaporated from the wire surface before reaching the extreme tip of the wire. Additional evidence is now offered to support this assumption.

When welding in argon with straight-polarity direct current, selected compounds of the alkali metals, the alkaline-earth metals or the rare-earth metals may be used to achieve spray transfer. Supposedly these compounds dissociate at temperatures reached near the tip of the wire and leave a thin layer of metallic atoms or ions which forms the highly emissive cathode surface. The fact that the boiling points of these metals are low lends credence to the possibility that they could be evaporated from the cathode surface before reaching the extreme tip of the wire.

Many of the compounds that produce spray transfer in an argon shield fail to do so in an atmosphere of carbon dioxide. Failure to achieve spray transfer may be due to chemical reactions between the compounds and the dissociated carbon dioxide in the arc; the coating compounds may be transformed to oxides. If these oxides are good emissive agents, both the cathode voltage drop and the melting rate of the wire would be lower than developed with an uncoated wire. However, it is postulated that spray transfer will not be produced if such oxides have boiling points which are too high to permit their evaporation before reaching the extreme tip of the wire. Under these conditions, the required cathode voltage drop over the molten end of the electrode would be uniformly low and the mechanism for preventing concentration of the welding current in a localized, high-current-density spot on the wire tip would no longer be present. Compounds of many of the alkaline-earth and rare-earth metals cause a reduction in electrode melting rate but do not produce spray transfer in carbon dioxide. It seems to be more than a coincidence that all of these metals can form oxides with very high boiling points; furthermore, many of these oxides are known to be good emissive agents.

Cesium may be able to produce spray transfer in carbon dioxide, because any oxides of cesium that might form have decomposition temperatures even lower than the boiling point of cesium itself. The spray producing ability of cesium is believed to be cancelled by the presence of alkaline-earth or rare-earth metals because, even though the cesium may leave the wire at the proper point, the refractory oxides of the other metals remain on the wire too long and serve to reduce the cathode voltage drop at the extreme tip of the wire.

When alkali-metal compounds are added to cesium compound coatings, the melting rate of the wire increases (Fig. 1). The mixture of compounds is less effective in reducing the cathode voltage drop than is the cesium compound alone. Therefore, it cannot be claimed that the lowering of transition current is caused by an increase in thermionic emission due to the presence of the added compound. One possible explanation of why the mixture is effective in reducing transition current is that, with such a combination, a eutectic mixture of the alkali metals (or their oxides) may be formed with a lower melting point and higher boiling point than associated with cesium alone. A lower melting point coating might spread more uniformly on the wire than would cesium. Furthermore, cesium has a very low boiling point and may leave the electrode at a point too high on the wire to be fully effective.

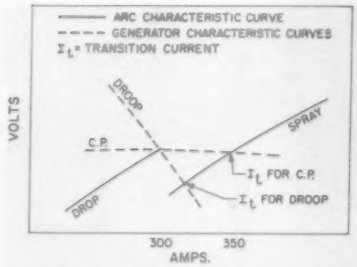

Fig. 4—Dependence of transition current on power supply characteristic

Raising the boiling point of the coating, even with a small sacrifice of thermionic emission, may permit the coating to stay on the wire longer and be effective within an area closer to the tip of the wire. It should be understood that the boiling point of the mixture, though higher than that of cesium, should not be so high that it would not be evaporated before reaching the extreme tip of the wire.

During spray transfer from a properly coated wire, the welding current is able to take the relatively long path to the sides of the wire rather than directly to the extreme tip if the total voltage drop across the longer current path is less than that across the short path. The high emissivity and low boiling point of cesium have been suggested as the means for making the cathode voltage drop at the side of wire less than that at the extreme tip. The current can take the longer path only if the increase in plasma voltage drop is less than the decrease in cathode voltage drop. However, with cesium in the arc, the increase in plasma voltage drop might be small due to the unusually low ionization potential of cesium. The plasma voltage gradient in carbon dioxide normally is quite high. However, when cesium evaporates from the wire and becomes part of the plasma, the voltage gradient may be lowered, thereby minimizing the increase in plasma voltage drop when the current takes the longer path.

Cesium may be unique in its effects on the mode of metal transfer in carbon dioxide because it combines the properties of low ionization potential, high emissivity, low boiling point and low dissociation temperature of its oxides.

Process Data

Firm recommendations have not been made yet as to the best procedure to be followed in each application of the new wire. Data are being collected in the development

Fig. 5—Specimens of butt welds after tensile and guided-bend tests

laboratory to determine optimum values of welding current, arc length, welding speed, etc., for each type of joint and plate thickness for which the process is applicable. The detailed results of these investigations are to be the subjects of future reports. However, sufficient process data have been gathered to substantiate several general statements.

Single-pass welds can be used to make high quality joints in plate as thin as $^1/_8$ in. Joints that can be fabricated in the flat position include the butt with square-edge preparation, the lap and the tee. Tee joints can also be welded in the horizontal position. Figure 5 is a photograph of test specimens from welded square-butt joints in $^1/_4$- and

Fig. 6—Cross section of square butt weld in $^1/_2$-in. plate, straight-polarity direct current with coated wire in carbon dioxide

Fig. 7—Cross section of multipass weld in 1-in. plate, straight-polarity direct current with coated wire in carbon dioxide

$^1/_2$-in. plate after the specimens were subjected to tensile and guided bend tests. Each of the tensile-test specimens failed in the plate material rather than in the weld. Though stronger than the plate material (semikilled steel), the welds were sufficiently ductile to withstand the bend test without cracking.

Square butt joints in $^1/_2$-in. thick plate can be welded in two passes, one on each side. The weld shown in Fig. 6 was made with a 0.045-in. diam wire, a 350 amp current, a $^1/_8$-in. arc length and 15 ipm welding speed.

Multipass welds can be made in heavy sections with no more than wire-brush cleaning between passes. Oxidation of manganese and silicon in the wire causes the formation of a complex-oxide slag on the surface of the weld. The slag protects the hot weld from the air and aids in forming a smooth surface. However, the slag cover is very thin and tends to free itself from the surface as the weld cools. It can be removed easily through use of an air blast or wire brush. Figure 7 is a photomacrograph of a section from a grooved corner weld in 1-in. thick plate and illustrates the macrostructure in such multipass welds. This six-pass weld was made with a 0.054-in. diam wire, a 380-amp current and a 15 ipm welding speed.

Typical tensile-test of all-weld-metal specimens taken from multipass welds are as follows: ultimate strength, 75,000 psi; yield strength, 64,000 psi; elongation in 2 in., 25%.

The carbon dioxide-shielded arc is more deeply penetrating than the conventional argon-shielded arc when operating under similar conditions. Figure 8 shows cross sections of two bead welds made with the same current (350 amp) and travel speed (15 ipm). One was made in argon with reverse-polarity current and an uncoated $^1/_{16}$-in. diam electrode wire; the other was made in carbon dioxide, with straight-polarity current, using the same wire, but coated with a mixture of cesium and sodium carbonates.

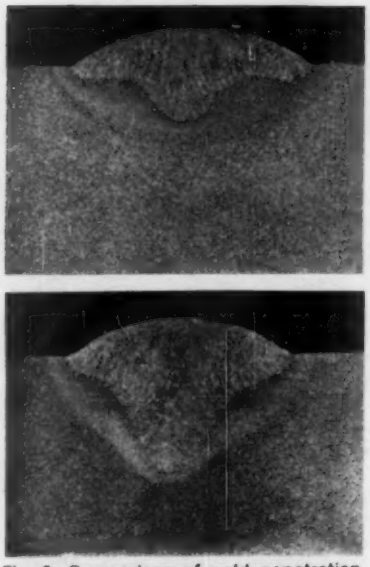

Fig. 8—Comparison of weld penetration patterns in argon and carbon dioxide. × 10 (upper view—reverse-polarity direct current, bare wire, in argon; lower view—straight-polarity direct current, coated wire, in carbon dioxide

The photographs of Fig. 9 show the difference between the bead-weld contour obtained when welding with a bare wire and conventional reverse-polarity, short-arc-length technique and the contour obtained when welding with a coated wire and the straight-polarity, long-arc-length technique. Each weld was made using 350 amp and a 0.045-in. diam wire. Of the two reverse-polarity welds, the one made with a "buried" arc produced little spatter, but the weld reinforcement was very narrow. Bead contour was improved when using a "zero" arc length, but spatter increased. The straight-polarity weld, made with a $^1/_8$-in. arc length, produced the best bead contour with a minimum amount of spatter.

Conventional, commercially-available equipment for gas-shielded metal-arc welding is used, without modification, with the new wire. Selection of welding current and wire diameter permits deposition rates within the range of 2 to 18

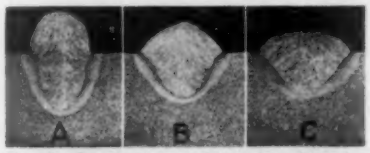

Fig. 9—Comparison of bead weld contours in carbon dioxide (A—reverse-polarity direct-current, bare wire, buried arc; B—reverse-polarity direct-current, bare wire, zero arc length; C—straight-polarity direct-current, coated wire, $^1/_8$-in. arc length)

lb/hr, with stable spray-transfer arcs.

Summary

Carbon dioxide has been used in place of argon in gas-shielded metal-arc welding of mild steel because of the difference in cost of the gases. However, the saving in gas costs has entailed a sacrifice of the spatter-free, spray transfer of electrode metal which previously has been available only in argon-shielded arc welding. Consequently, a method was sought for improving the mode of metal transfer in carbon-dioxide-shielded arc welding.

Electrode wires containing only a small amount of deoxidizers such as silicon and aluminum could be made to produce spray transfer in carbon dioxide by coating the wire with a cesium compound and operating with straight-polarity direct current. However, the resulting welds were porous. Increasing the deoxidizer content of the wire improved the soundness of the weld metal but had an adverse effect on the mode of metal transfer; transition currents were abnormally high, arc action was erratic, and test results could not always be duplicated.

The effects on the arc of a cesium compound were changed significantly by adding other emissive agents to the coating. Some of the additives impaired the spray-producing action of the cesium; others improved arc stability, lowered transition current, and made spray transfer possible with highly deoxidized wires which could not be treated successfully with cesium compounds alone.

By adding one of the compounds of either sodium, potassium, or rubidium to a cesium compound so that the two metal atoms are present in equal atomic concentrations and then coating this mixture on welding wire, spray transfer can be achieved with wires containing a large amount of deoxidants.

The mode of metal transfer is similar to that obtained in argon with reverse-polarity direct current. The welds are sound and ductile. In addition the carbon dioxide-shielded arc is deeply penetrating. When compared with conventional reverse-polarity carbon dioxide-shielded arc welding, welding with the new electrode has the advantages of spatter-free metal transfer, freedom from the need to control arc length accurately and to maintain a short arc and an improved shape of weld reinforcement.

Acknowledgment

The author is indebted to Dr. A. Lesnewich for his extensive contributions to this investigation.

WRC Bulletin No. 64

Web Buckling Tests on Welded Plate Girders

Welding Research Council Bulletin No. 64, published in September 1960, constitutes a report on the experimental phase of an investigation carried out at Lehigh University with the purpose of determining the static carrying capacity of welded plate girders. The Bulletin is presented in four parts which are as follows: (1) The Test Girders; (2) Tests on Plate Girders Subjected to Bending; (3) Tests on Plate Girders Subjected to Shear; (4) Tests on Plate Girders Subjected to Combined Bending and Shear. The objective of the investigation was to determine the postbuckling strength of thin web plate girders in order to clarify uncertainties such as what factor of safety should be used for web buckling due to shear and web buckling due to bending. Also, information was obtained as to the actual carrying capacity of welded plate girders. Based on the information presented in this Report and information from the theoretical part of this investigation, design recommendations will be made. Sponsored jointly by the American Institute of Steel Construction, the U. S. Department of Commerce (Bureau of Public Roads), Pennsylvania Department of Highways and the Welding Research Council, the research project at Lehigh University was guided by the "Welded Plate Girder Project Subcommittee" of the Welding Research Council.

The price of this Bulletin is $2.00. Single copies may be purchased from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y. Quantity lots may be purchased from the Welding Research Council, 29 W. 39th St., New York 18, N. Y.

Arc Welding of a Ni-Cr-Fe (Inconel) Alloy for Nuclear Power Plants

Paper sponsored by ASME
describes structural and cladding weld tests
as carried out with three shielded-arc processes,
using Inconel-type filler metals containing
Cb, Cb-Mn or Ti additions

BY JAY BLAND AND W. A. OWCZARSKI

ABSTRACT. The use of a high-nickel, Ni-Cr-Fe alloy (Inconel) is being considered in nuclear power plants because, in certain media, it has stress-corrosion resistance which is superior to that of austenitic stainless steels. The fabricating of this alloy will require its welding for structural members and for overlaying carbon steel with Inconel-type filler metals. This report describes the results of an investigation which has been made of the arc welding of Inconel, using commercially available filler metals and the shielded-metal - arc, inert - gas tungsten - arc, and inert-gas metal-arc welding processes.

Weldments meeting the high-quality standards required for nuclear power plant service can be made with all of the filler metals and processes studied. In general, all structural welds of Inconel to itself, to Type 304 stainless steel, or to carbon steel failed in the weaker base metal when tested for static tensile properties. All-weld-metal mechanical properties of the Inconel-type filler metals exceeded those of the annealed wrought base metal.

Covered electrodes for welding Inconel exhibit somewhat more difficult usabilities than do the standard stainless-steel electrodes. In particular, out-of-position welding with the Inconel-type electrodes is limited to smaller sizes, and the deposits exhibit more porosity than for stainless-steel electrodes. A characteristic tenacity of the slag produced by the Inconel-type covered electrodes contributes to the more difficult usability characteristics.

Inconel-type filler metals are modified by additions of Cb, Cb-Mn or Ti for specific applications. The Cb-modified filler metals are intended for similar metal welds; the Cb-Mn modified, and the Ti-modified filler metals are used for dissimilar metal welds. Both the Cb- and Ti-modified filler metals, when welding with the shielded metal arc or the inert-gas metal-arc welding processes, produce deposits which exhibit fissures of various sizes, depending on several factors. The bare wire filler metals, used with the manual inert-gas tungsten-arc welding process, usually produce fissure-free deposits. These fissures, which are detected in metallographic examination and in bend tests, are intergranular and appear to be caused by the segregation of some low strength phase during solidification of the weld deposits. The Cb-Mn modified electrodes deposit weld metal essentially free from porosity and fissures.

The Ti-modified, bare wire filler metal deposit is susceptible to precipitation-hardening when postweld heat-treated in the temperature range of 1050 to 1300° F. depending on time at temperature. The temperatures and times of precipitation-hardening are within the normal postweld thermal stress-relief treatments required by applicable codes for structural members containing carbon steel. Hardened deposits exhibit a serious decrease in ductility and toughness properties, particularly when fissures are present. Bend test failures of precipitation-hardened deposits provided evidence of the loss in ductility.

Weld deposited overlays made with the Inconel-type filler metals on carbon steel exhibit bend properties comparable to those of structural butt weld deposits. Iron dilution of the alloy deposit will vary with technique and/or process used; generally, the second and succeeding layers will contain less than about 15% total iron. Preliminary data indicate that this level of iron in the Inconel deposit will not adversely affect its general corrosion or stress corrosion cracking resistance.

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Paper presented at AWS 41st Annual Meeting held in Los Angeles, Calif., Apr. 25–29, 1960.

Introduction

A nickel-chromium-iron alloy (Inconel) was selected for some components of a nuclear power plant because of its better resistance to stress-corrosion cracking than the 300 series stainless steels. This nickel-base alloy is a weldable material, but weldments had not been produced or inspected to the quality levels required for nuclear service, nor had the alloy been welded in section thicknesses required for some components of this plant.

Inconel has been used commercially for many years as a corrosion and high-temperature resistant material. Its application as a structural material has been limited; and within this application, information has not been accumulated comparing the soundness and mechanical properties of welds made with Inconel-type filler metals and the various welding processes. As the wall thickness of a component increases, a point is reached where the combination of cost and weight for a solid Inconel fabrication makes it feasible to consider a clad vessel. Some Inconel weld cladding has been used in commercial applications. However, nuclear plants present somewhat new corrosion conditions and reliability requirements. Minor changes in corrosion resistance due to base metal dilution, previously of little or no consequence, may alter the accessibility to a nuclear plant significantly.

Table 1—Nominal Compositions of Deposited Inconel-type Filler Metals and of Several Base Metal Alloys

	Code	Nominal chemical composition, %[a]										
		C	Mn	Si	S	Cr	Ni	Fe	Cb	Al	Ti	Others
Electrode A[b]	A	0.15	1.5	0.40	0.015	13.0/17.0	68.0 min	11.0	1.5/4.0	...	...	Cu 0.50
Electrode B[b]	B	0.15	1.5	0.75	0.015	13.0/17.0	68.0 min	11.0	1.5/4.0	...	...	Cu 0.50
Electrode C[b]	C	0.15	1.0/3.5	0.75	0.02	13.0/17.0	Balance	6.0/12.0	1.0/3.0	...	...	Cu 0.50 Mo 0.50/2.0
Electrode D[b]	D	0.15	1.5	0.75	0.015	17.5 min.	70.0 min	4.0	1.5/4.0	...	...	Cu 0.50
Electrode E[b]	E	0.10	1.0	0.75	0.015	14.0/17.0	70.0 min	6.0/10.0	Min 4× Si	...	...	1.0
Electrode F[b]	F	0.10	5.0/9.5	1.00	0.015	13.0/17.0	Balance	6.0/10.0	1.0/2.5	...	...	1.0 0.50
Wire G[c]	G	0.10	1.0	0.75	0.015	14.0/17.0	70.0 min	6.0/10.0	Min 4× Si	...	...	1.0
Wire H[c]	H	0.10	2.0–2.75	0.35	0.015	14.0/17.0	67.0 min	10.0	...	0.10	2.50/3.50	Cu 0.50
Wrought Inconel[d]	Inconel	0.10	1.0	0.50	0.015	14.0/17.0	72.0 min	6.0/10.0	...	...	...	Cu 0.50
304 L stainless steel[e]	304L	0.03	2.00	1.00	0.03	18.0 min	8.0 min	Balance	...	...	...	P 0.035
ASTM-A212,[f] grade B	A212	0.31	0.90	0.15/0.30	0.04	...	...	Balance	...	...	...	P 0.035

[a] All values are maximum unless otherwise stated.
[b] MIL-E-17496 and addenda.
[c] MIL-E-21562 and addenda.
[d] ASTM B-168-58T, except C, 0.10 max; Co, 0.01 max.
[e] MIL-S-18170.
[f] ASTM A212-57T.

A welding program was undertaken (1) to determine if the necessary butt welds and weld overlays could successfully be made for the reactor components and (2) to determine the advantages and disadvantages associated with the various welding products and processes. The evaluation program covered structural welding and weld overlays; some study was made of the effects of postweld heat-treatments. The structural welding work investigated the deposit soundness and mechanical properties of the Inconel-type filler metal in $1^1/_8$ and $2^5/_8$-in. thick butt joints. The overlay work included an evaluation of the mechanical properties and soundness of covered-electrode and inert-gas-shielded arc welded overlays on carbon steel. The program was also intended to disclose if fabrication of welded Inconel components would introduce unusual difficulties as compared with fabrication of 300 series stainless-steel components.

All welding was done in the downhand (flat) position, since most component fabrication permits positioning. Extensive efforts were not made to establish optimum welding conditions for each weld. However, before making any test weldment, reasonably satisfactory deposition characteristics were developed. The Inconel-type filler metals and base metals studied in the program are listed in Table 1 together with their nominal chemical compositions.

Weldments included in each phase were tested to radioactive system quality and inspection standards. Nondestructive tests were made in accordance with Military Standard MIL-STD-271; radiographic evaluation was based on Group I standard of NAVSHIPS 250-692-2 (1957). Mechanical testing was done in accordance with Military Standard MIL-STD-278.

Structural Welding of Inconel

A series of $1^1/_8$-in. thick butt welds was made and tested in order to accumulate comparative information for the various Inconel-type filler metals, and to determine the fabrication advantages and disadvantages which might be connected with each material involved. A series of $2^5/_8$ in. thick butt welds also was made to determine if increasing thickness might increase quality or fabrication difficulties. Prior to depositing the test weld, sufficient welding was performed to determine the current range for the covered electrodes that gave the best slag removal and bead contour, and to determine the conditions which gave the combination of satisfactory arc characteristics and bead contours for the inert-gas processes.

Procedure and Results

The covered electrode welds, which were made, are listed in Table 2. Welds joining Inconel to itself and to stainless steel were tested in the as-welded condition. Inconel to carbon steel welds were stress-relieved at 1150° F prior to testing so as to simulate the fabrication heat-treatment required for carbon steel vessels. The $1^1/_8$-in. thick welds were held at temperature for 4 hr, and the $2^5/_8$-in. thick welds were held at temperature for 6 hr. Root passes for all of the covered electrode welds were deposited by the manual inert-gas tungsten-arc process with argon backing. Code G filler metal was added to the Inconel to Inconel welds, and Code H filler metal was added to the dissimilar metal welds. The welds were restrained U-groove butt joints with the weld preparations as shown in Fig. 1. The filler metal was deposited with a stringer bead technique, using a short arc length and a 15 to 20° lead angle. No preheat was used, and interpass temperatures did not exceed 250° F. The currents used were in the intermediate range of those suggested

Table 2—Covered Electrode Welds

Base metals	Filler metal code	Joint design (Fig. 1)	Base metal thickness, in.	Total no. weld passes
Inconel to Inconel	A	A	$1^1/_8$	42
Inconel to Inconel	B	A	$1^1/_8$	43
Inconel to Inconel	E	A	$^3/_4$	29
Inconel to Inconel	F	A	$1^1/_8$	39
Inconel to 304L	C	A	$1^1/_8$	42
Inconel to 304L	F	A	$1^1/_8$	37
Inconel to A212	C	A	$1^1/_8$	44
Inconel to A212	F	A	$1^1/_8$	35
Inconel to Inconel	B	A	$2^5/_8$	162
Inconel to Inconel	F	A	$2^5/_8$	124
Inconel to A212	C	A	$2^5/_8$	134
Inconel to A212	F	A	$2^5/_8$	120

by the electrode manufacturer.

Table 3 shows the automatic inert-gas metal-arc welds which were made. These welds were restrained U-groove butt joints with preparations as shown in Fig. 1. No preheat was used for these welds, and interpass temperatures were held below 250° F. The deposit technique was stringer beads (no oscillation) with about 1/8-in. overlap of the previous bead. Gas coverage was 50 cfh high-purity, welding-grade argon. The electrode extension was held constant at 3/4 in. The gas cup to work distance was held constant at 1/2 in. The welding conditions are tabulated in Table 4 for these welds.

Each weld was nondestructively evaluated by liquid penetrant and radiographic inspections; the welds then were sectioned for room temperature and elevated temperature tensile tests, transverse guided side bend tests, hardness and metallographic examinations.

The results of mechanical tests for the 1 1/8-in. plate weldments are summarized in Table 5. Results for the tests made from the 2 5/8-in. thick welds are summarized in Table 6. Photographs of some of the mechanical test specimens and of the metallographic examinations are shown in Figs. 2 to 20, inclusive.

All of the butt welds were subjected to liquid penetrant and radiographic inspection. Liquid penetrant testing was done for the root pass, at the 3/8-in. level, and after the completion of welding. Radiography was done only after completion of welding. All but two of the butt welds successfully passed these tests. Both the 1 1/8 and 2 5/8-in. thick Inconel-to-Inconel joints welded by the automatic inert-gas metal-arc process, using Code F wire, were considered rejectable, although several indications shown during the liquid penetrant test had been ground out and locally repaired. The 1 1/8-in. butt weld contained excessive porosity and linear indications; the 2 5/8-in. weld exhibited only linear indications, probably caused by unfused regions.

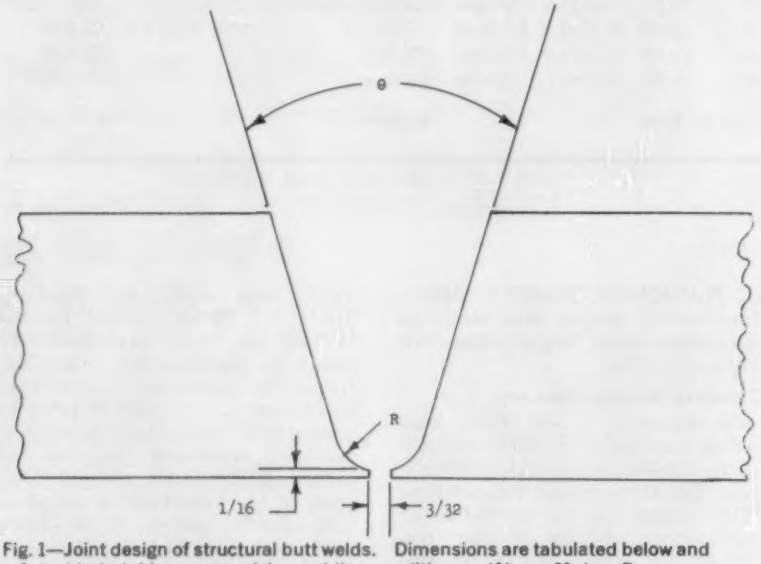

Fig. 1—Joint design of structural butt welds. Dimensions are tabulated below and referred to in tables summarizing welding conditions. (A) $\theta = 30$ deg, R = 5/16 in.; (B) $\theta = 50$ deg, R = 3/16 in.; (C) $\theta = 60$ deg, R = 3/16 in.

Table 3—Automatic Inert-gas Metal-arc Welds

Base metals	Filler metal code	Joint design (Fig. 1)	Base metal thickness, in.	Total no. weld passes
Inconel to Inconel	G	C	1 1/8	29
Inconel to 304L	H	C	1 1/8	23
Inconel to A212	H	B	1 1/8	25
Inconel to Inconel weld-clad A212	H	B	1 1/8	30
Inconel to Inconel	G	A	2 5/8	49
Inconel to A212	H	A	2 5/8	76

Table 4—Automatic Inert-gas Metal-arc Welding Conditions

Base metals	Arc voltage	Current, amp (DCRP)	Wire feed speed, ipm	Travel speed, ipm	Electrode position
Inconel to Inconel (0.045 in. diam G wire)	27–28	170–185	380–400	14	Vertical, no tilt
Inconel to Type 304L (0.045 in. diam H wire)	29–30	230–250	450–570	10–12	Vertical, no tilt
Inconel to Carbon Steel, (0.062 in. diam H wire)	23–24	250–300	220–250	18–22	Vertical, 10 deg tilt
Inconel to Inconel-clad Carbon Steel (0.062 in. H wire)	23–24	250–330	230–280	18–22	Vertical, 10 deg tilt
Inconel to Inconel[a] (0.062 in. diam G wire)	29–30	260–310	230–260	12	Vertical, 10 deg tilt
Inconel to Carbon[a] Steel (0.062 in. diam H wire[a]	23–24	250–290	170–200	13–17	Vertical, 10 deg tilt

[a] 2 5/8 in. thick joint.

Discussion

The use of proper welding techniques is essential to the production of sound Inconel weldments. This is true with both the metal arc and inert-gas-shielded metal-arc processes. Inconel covered electrodes have hygroscopic coverings and may require baking prior to use since moisture in the coverings has been found to produce excessive porosity. Oven baking at 500° F for 2 hr is one electrode manufacturer's recommendation, but lower temperatures may be adequate depending upon the storage history of the electrode.

The usability of the Inconel-covered electrodes is considerably different from that of stainless-steel electrodes, in that the Inconel electrode should be used with a shorter arc length and more limited weaving (less than 1 1/2 core wire diameters). It has been found that welding operators experienced with stainless steel covered electrodes have required additional training before being able to produce satisfactory Inconel welds. In the downhand position, excessive porosity and slag entrapment are the inevitable results of improper tech-

Table 5—Mechanical Test Results for 1⅛-in. Structural Welds

Materials	Transverse tensile tests (.505 in. diam)			Side bend tests, No. of fissures		Hardness, Rockwell A		
	Temp. of test, °F	Ultimate strength, psi[a]	Failure	spec. 1	spec. 2	Weld metal	Base metal	
							Inconel	Other
Inconel to Inconel	80	87,800	Base metal	4	4	56.4	46.0	46.0
Code A electrode	650	84,800	Base metal					
Inconel to Inconel	80	88,000	Base metal	2	1	56.6	47.0	47.0
Code B electrode	650	84,000	Base metal					
Inconel to Inconel	80	107,200	Weld deposit[b]	1	0	57.6	58.3	57.6
Code E electrode								
Inconel to Inconel	80	91,500	Base metal	0	0	56.3	46.5	46.5
Code F electrode	650	86,500	Base metal					
Inconel to Inconel	80	89,500	Base metal	1	1	54.2	46.0	47.0
Code G wire[d]	650	85,800	Base metal					
Inconel to 304L	80	82,300	304 base metal	2	0	56.9	48.0	47.0
Code C electrode	650	58,300	304 base metal					
Inconel to 304L	80	86,000	304 base metal	0	0	56.3	46.0	47.0
Code F electrode	650	59,800	304 base metal					
Inconel to 304L Code H wire[d]	80	85,500	304 base metal	2	2[c]	54.9	48.0	44.0
Inconel to A212 Code C electrode,	80	83,700	A212 base metal	3	0	56.9	46.0	51.0
heat-treated 4 hr at 1150° F	650	83,200	A212 base metal					
Inconel to A212 Code F electrode,	80	83,700	A212 base metal	0	0	56.3	46.0	50.0
heat-treated 4 hr at 1150° F	650	81,600	A212 base metal					
Inconel to A212 Code H wire,[d]	80	65,400	A212 base metal	4	5	62.4	50.0	44.0
heat-treated 4 hr. at 1150°F.	650	65,700	A212 base metal					
Inconel to A212 Code C electrode,	80	76,800	A212 base metal	6	2	56.4	47.0	49.0
heat-treated 8 hr at 1300° F	650	79,900	A212 base metal					
Inconel to Code H wire overlayed	80	74,000	A212 base metal	6[c]	7[c]	62.3	47.0	57.0 (overlay)
A212 with Code H wire,[d] heat-treated 4 hr at 1150° F	650	69,500	A212 base metal					44.0

[a] Tensile values are the average of three tests which were performed on as-welded material unless otherwise stated.
[b] Base metal severely cold-worked.
[c] Contains fissures over 1/16 in., but not over 1/8 in. in length.
[d] Automatic inert-gas metal-arc process.

nique. The slags produced by the Inconel electrodes tested, except for the Code F electrode, are very tenacious and difficult to remove. Each layer must be thoroughly cleaned since there is no tendency for slag to float out during subsequent passes. The Code F electrode slag, except in restricted portions of grooves, is almost self-removing.

Improper bead contour and weld current control usually add to slag removal difficulties. Excessively narrow joints which are too restrictive for adequate electrode manipulation may also contribute to the welding difficulties.

The welds made with covered electrodes during this program were all U-groove butt joints with 30 deg total included angle and 5/16-in. root radius. This design proved satisfactory.

The automatic inert-gas metal-arc process presents different problems. Slag entrapment is not a problem, but other defects can be introduced by improper operator technique, joint design, inadequate control of weld conditions and certain characteristics of the molten weld metal. Joint openings must be wider for automatic inert-gas metal-arc welding than for covered electrode welding. A total included angle of 50 deg and a root radius of 3/16 in. were found to give satisfactory results. Joint bevels of less than 25 deg caused difficulties in obtaining adequate side wall fusion.

Molten Inconel-wire filler metal deposits do not have good wettability and fluidity. The fringes of the molten beads tend to lap over the solid portion of the walls and cause regions of lack of fusion. Some of the first automatic inert-gas metal-arc welds prepared contained these areas of lack of fusion. However, these defects were eliminated through careful bead placement and parameter control in later joints. In some cases, tilting the torch was used to compensate for narrow joint openings. In general, weld parameters producing smaller bead sizes were more satisfactory because of the ability to better control bead contours.

All the 1 1/8-in. plate transverse butt tensile test results, as reported in Table 5, were satisfactory with base metal failure in all cases but one. This single case of weld metal failure exhibited strength well above the minimum value for annealed Inconel base metal; an investigation disclosed that the base metal was severely cold worked.

Table 6—Mechanical Test[a] Results for 2⅝-in. Structural Welds

Filler metal	All-weld metal tensile tests (0.505 in. diam) Test temp, °F	Ultimate strength, psi	Yield strength 0.2% offset, psi	Elongation, in 2 in., %	Reduction of area, %	Side bend tests, no. of fissures Specimen no., 1 2 3 4	Hardness, Rockwell A Weld metal	Inconel base metal	Other base metal
Inconel to Inconel	80	93,000	60,700	39.6	50.7	3 3 5 7	57.3	45.0	45.0
Code B electrode	650	93,700	61,500	38.5	47.4				
Inconel to Inconel	80	92,800	58,200	35.0	35.0	1 1 1 1	56.3	46.0	46.0
Code F electrode	650	87,500	51,200	47.0	47.0				
Inconel to Inconel	80	91,600	56,500	41.0	53.3	6 6 2 5	54.7	45.0	46.0
Code G wire[c]	650	82,500	46,100	47.8	51.8				
Inconel to A212, Code H wire[c]	80	95,300	91,500	4.5	11.8	Badly fissured, all 4 samples broke at a 45° bend.	63.2	47.0	43.0
heat-treated 6 hr at 1150° F	650	111,600	84,900	32.3	34.2				
Inconel to A212, Code F	80	98,500	64,500	25.0	26.0	3 0 0 0	56.3	46.0	44.0
electrode, heat-treated 6	650	95,400	60,000	45.0	45.0				
hr at 1150° F									
Inconel to A212 carbon steel,	80	95,900	59,800	36.2	39.9	20 6[b] 10 6	57.4	44.0	43.5
Code C electrode, heat-	650	85,300	50,800	40.7	47.2				
treated 6 hr at 1150° F									

[a] Tests conducted on as-welded material unless otherwise designated. Tensile test results are average of three tests.
[b] Contained fissures over 1/16 in., but not over 1/8 in. in length.
[c] Automatic inert-gas metal-arc process.

Some of the weldments in the power plant which contain carbon steel require postweld thermal stress-relief treatments to meet ASME code requirements. All welds made in the program, which involved carbon steel as one of the base metal members, were stress-relieved at 1150° F prior to mechanical testing, with the exception of one Code C electrode weld. This weld was given a 1300° F thermal treatment for 8 hr to study any possible precipitation-hardening effects on the structural properties of this filler metal. The results indicated that the heat-treatment did not affect the mechanical properties.

All-weld-metal specimens taken from the 2⅝-in. thick structural welds provided tensile properties for five of the Inconel-type filler metals (Codes G and H wires; Codes B, C and F electrodes). The Code H wire and the Codes C and F electrodes were tested in the heat-treated condition, since their major usage would be for dissimilar carbon steel weldments. All tensile and ductility properties of the Code G wire and Codes B, C and F electrodes exceeded the minimum values for Inconel, carbon steel or type 304 stainless-steel base metals. Only the Code H wire, heat-treated at 1150° F for 6 hr, showed undesirable properties, with an elongation of 4.5% in 2 in. This compares with values of from 36 to 47% for the other filler metals.

Cross sections of each weldment were surveyed for hardness. Typical survey results are shown in Fig. 20. The results show only a slight variation across the weld deposit. All the as-welded deposits had nearly the same hardness. Only thermally-aged Code H wire deposits showed a significantly different (increased) hardness.

The bend tests from each welded joint provided additional information concerning the ductility and fissuring tendency of each type weld deposit. It is concluded that almost all of the Inconel weld deposits tested are subject to fissuring, but that the degree is dependent on the welding conditions and varies with each filler metal type. The fissures appear to be intergranular in nature and associated with a grain boundary constituent. This constituent probably is due to a combination of chemistry and cooling rate which causes the segregate to form in grain boundaries. An unusually heavy concentration of the grain boundary constituent is shown in Fig. 21.

The significance of the fissures is not completely understood. As can be seen from the results of the bend and tensile tests, some weld deposit properties are not detrimentally affected by the presence of fissures. All specimens, except the hardened Code H wire welds, bent 180 deg without propagation of fissures. The fissures do, however, have an effect on hardened Code H wire deposits. The failure in the bend tests (Fig. 7) indicates that precipitation-hardened Code H wire deposits may have poor notch-toughness properties and become sensitive to the presence of fissures under load. The low elongation

Table 7—Welding Conditions for Inconel Overlays

A. Covered electrode deposits

Electrode	Code A	Code C	Code D	Code F
Electrode size, in.	5/32	5/32	5/32	5/32
Current, amp (DCRP)	126–136	120–130	124–128	116–124
Deposition	Overlapping stringer	Overlapping stringer	Overlapping stringer	Overlapping stringer
Approx. travel speed, ipm	6	6	6	6–8
Total buildup, in.	5/16	5/16	5/16	5/16
Coverage, passes, in.	5	5	5	5

B. Inert-gas-shielded overlay deposits

Process	Auto. metal-arc	Auto. tungsten-arc	Manual metal-arc
Filler metal, wire	Code H	Code H	Code H
Wire diam, in.	0.062	0.062	0.045
Current, amp	260–290	290–310	120–150
Current, type	DCRP	DCRP	DCRP
Wire speed, ipm	185	50–60	380–430
Travel speed, ipm	10–12	7–8	8–10
Gas cup size	No. 14	No. 10	No. 10
Gas flow, argon, cfh	55	30	55
Deposition technique	Overlapping stringer bead	Overlapping stringer bead	3/4-in. weave, overlapping
Total buildup, in.	7/16	5/16	5/16

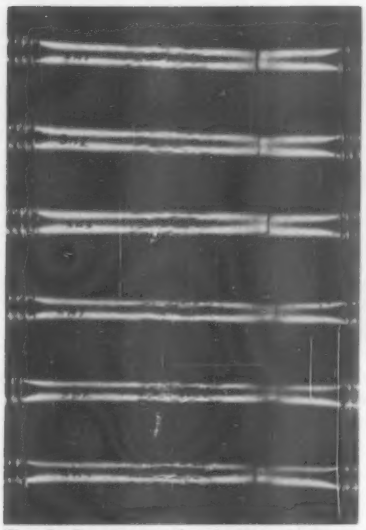

Fig. 2—Representative butt weld transverse tensile specimens, tested at 80° F (A-series) and at 650° F temperature (B-series), showing base metal failure. Inconel to Inconel, Code B electrode (as deposited)

in the tensile tests from the same deposit further supports this conclusion. The fissures seen in Fig. 7 are much larger than those generally noted; some have propagated to the point of low-ductility rupture, the extreme result of the combination of high hardness, poor notch toughness and fissures.

The use of Code H wire in components which undergo postweld thermal treatments must be cautiously considered because of the precipitation - hardening effects. Bend test data have shown that, in general, covered electrodes and automatic inert-gas metal-arc wire deposits are about equally susceptible to fissuring. Heat-treated Code C electrode and Code H wire weld deposits exhibited more fissures in bend tests than did as-welded deposits. The Code F electrode deposits were found to be the most fissure-free of all of the filler metal deposits tested.

Metallographic examination indicated that all fissures were not opened on weld freezing and initial cooling, but that some opened due to strain effects on the grain boundary constituent during bending.

Defects were observed in the heat-affected zone of $2^5/_8$ in. thick Inconel plate used for the heavy section joints. Metallographic examination revealed these defects were intergranular in nature and located adjacent to the fusion line of the heat-affected zone. Figure 19 shows one of these defects, which appears similar to previously mentioned weld-metal fissures.

Some of the heat-affected zone fissures were propagated into the weld metal, since weld-metal grain boundaries tend to align with those

Fig. 5—Bend test specimens from $1^1/_8$-in. Inconel to A212 joint welded with Code H wire filler metal (automatic inert-gas metal arc). Heat-treated at 1150 ° F for 4 hr. Shows few scattered defects

of the base metal as shown in Fig. 17. Similiar base metal difficulties have been reported by others engaged in Inconel welding.

Increasing plate thickness did not increase weldability problems. Fissure frequency per unit area did not increase, nor was there any decrease in ductility attributable to increased plate thickness. Failure of the hardened Code H wire deposit in the heavy section was attributed to hardness and fissures rather than to section thickness increase.

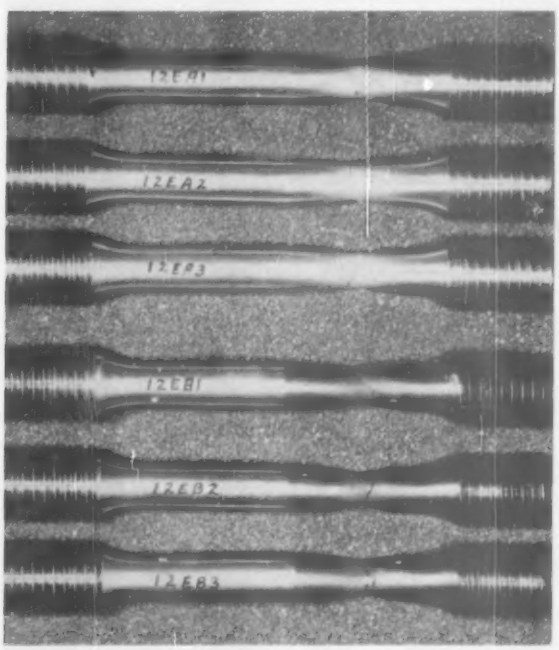

Fig. 3—Butt weld transverse tensile specimens, tested at 80° F (EA series) and at 650° F (EB series), Inconel to A212 joint, Code H wire filler metal (automatic inert-gas metal arc). Heat-treated at 1150° F for 4 hr

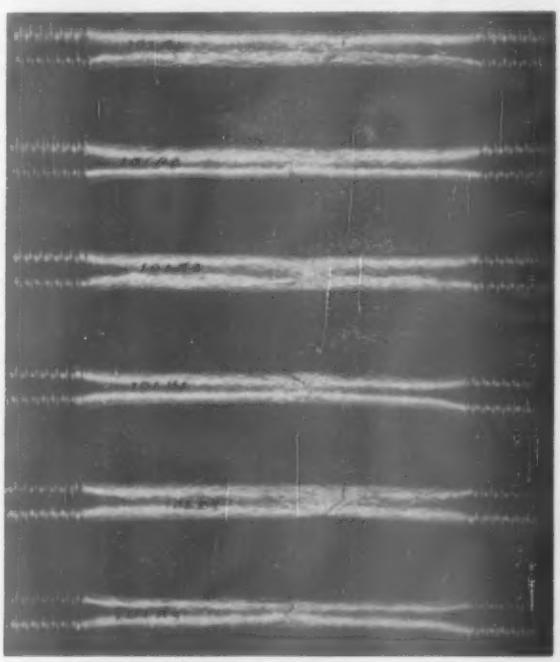

Fig. 4—All-weld-metal tensile specimens, tested at 80° F, Code B electrode filler metal (as deposited)

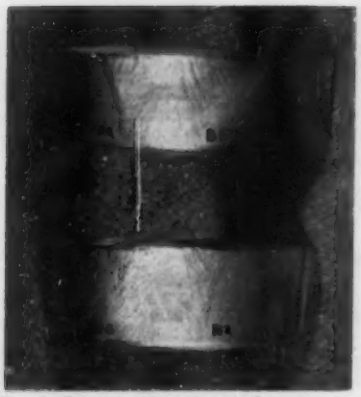

Fig. 6—Bend test specimens from $1^1/_8$-in. Inconel to A212 joint welded with Code C electrode filler metal. Heat-treated at 1150° F for 4 hr. Shows no visible defects

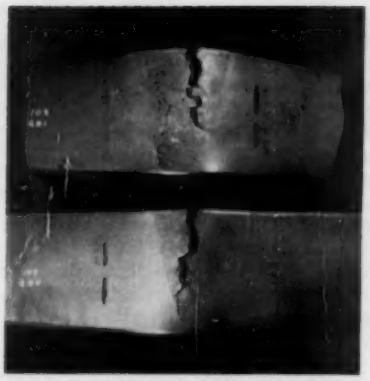

Fig. 7—Bend test specimens from heavy section Inconel to A212 joint ($2^5/_8$ in.) welded with Code H wire filler metal (automatic inert-gas metal arc). Heat-treated at 1150° F for 6 hr. Shows failure by severe cracking

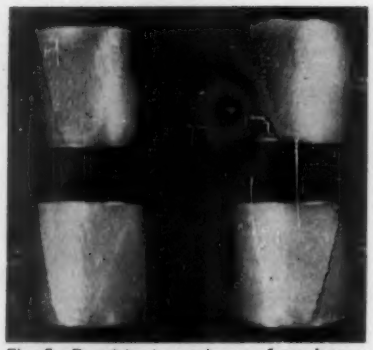

Fig. 8—Bend test specimens from heavy section ($2^5/_8$ in.) Inconel to A212 joint, welded with Code C electrode filler metal. Heat-treated at 1150 ° F for 6 hr

Inconel Cladding

The weld cladding processes and filler metals were compared on the basis of the deposit composition, quality and fabrication advantages. A series of three layer overlay clad plates was made and nondestructively tested by liquid penetrant and X-ray examinations. Side and face bend tests and metallographic examination completed this evaluation.

Procedure and Results

Carbon steel plates, 1 in. thick, were overlayed with the following filler metals:

1. Code A electrode
2. Code C electrode
3. Code D electrode
4. Code F electrode
5. Code H wire—deposited by automatic inert-gas metal-arc and inert-gas tungsten-arc, and manual inert-gas metal-arc processes.

The overlays were deposited in three layers on A212 carbon steel base metal plates as shown in Figs. 22 to 25. The welding conditions are given in Table 7. The plates were restrained by welding to a back-up plate.

The completed plates were stress-relieved at 1150° F for 4 hr. Each

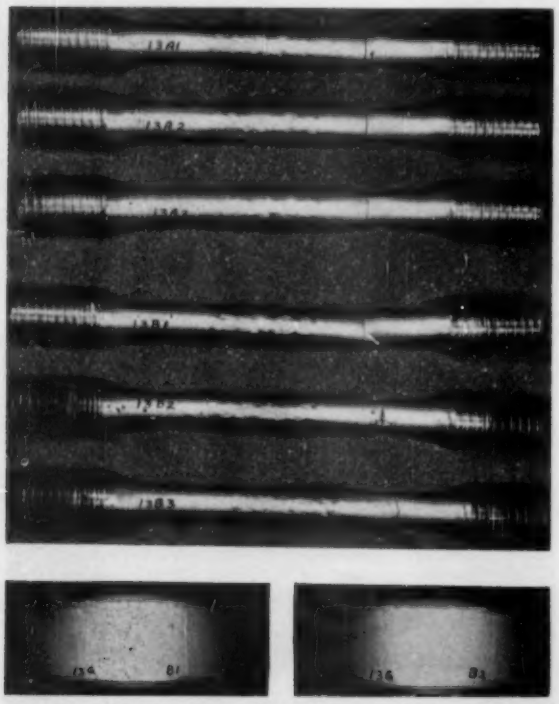

Fig. 9—Butt weld transverse tensile test specimens and transverse guided side bend specimens from $1^1/_8$ in. thick Inconel to Inconel joint welded with Code F electrode filler metal (upper three tensile specimens tested at 80° F—lower three at 650°F). All failures are in base metal

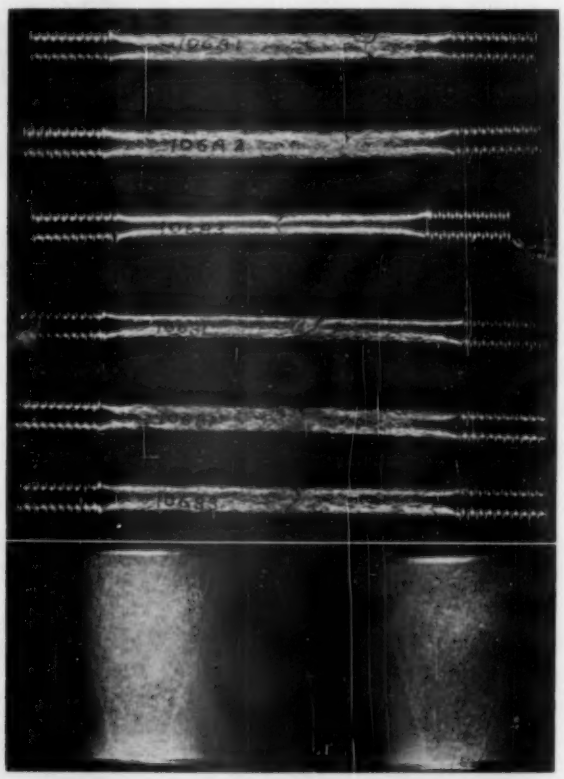

Fig. 10—All-weld metal tensile test specimens and transverse side bend test specimens from $2^5/_8$ in. thick Inconel to Inconel joint, welded with Code F electrode filler metal (upper three tensile specimens tested at 80° F—lower three 650° F)

Fig. 11—Inconel to Inconel joint welded with Code F electrode filler metal (groove weld, $1^1/_8$-in. thick plate), as-welded

Fig. 12—Inconel to 304L stainless steel (right) joint, welded with Code F electrode filler metal (groove weld, $1^1/_8$-in. thick plate), as-welded

Fig. 13—Inconel to A212 carbon steel (left) joint, welded with Code F electrode filler metal (groove weld, $1^1/_8$-in. thick plate). Heat-treated 1150° F for 4 hr

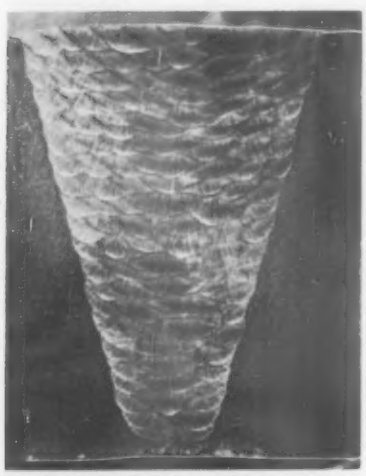

Fig. 14—Inconel to Inconel joint welded with Code F electrode filler metal (groove weld, $2^5/_8$-in. thick plate), as-welded

Table 8—Nondestructive and Hardness Test Results of Inconel type Weld Overlays on A212 Plate

	Nondestructive tests		Hardness survey (Rockwell A values)			
			Layer			Base
Filler metal	Liquid penetrant	Radiography[a]	3rd	2nd	1st	metal
Code A electrode	All layers acceptable	Acceptable	52.3	54.2	55.2	51.0
Code C electrode	All layers acceptable	Acceptable	52.0	53.8	55.0	51.0
Code D electrode	Some indications from surface porosity	Rejected—excess porosity	55.7	58.0	57.5	51.0
Code F electrode	All layers acceptable	Acceptable	56.3	...	...	51.0
Code H wire (auto. inert-gas metal-arc)	All layers acceptable	Acceptable	58.4	61.0	60.6	51.0
Code H wire (auto. inert-gas tungsten-arc)	All layers acceptable	Rejected—excess porosity and linear defects	59.0	59.0	61.6	43.0
Code H wire (manual inert-gas metal-arc)	All layers acceptable	Acceptable	55.3	57.0	53.5	43.0

[a] Radiographic results were similar before and after heat treatment.

layer of the cladding was liquid penetrant inspected and hardness checked and the final cladding was radiographed before and after heat-treatment. The results are summarized in Table 8.

Longitudinal and transverse side bend and transverse face bend test results are reported in Table 9. The numerous small fissures in the Code A electrode face bends and the fewer number in the Code C electrode face bends were parallel to the direction of welding. Side and face bend tests of the Code H wire automatic inert-gas metal-arc weld exhibited cracking across the entire overlay. Transverse side bend tests from the Code H wire automatic inert-gas tungsten-arc overlay also exhibited large cracks.

Chemical analysis results from each layer of the overlays are reported in Table 10. Figures 26 through 28 show the bend test specimens for the clad plates.

Discussion

Overlays deposited with even the larger size covered electrodes have been found to be comparatively time-consuming. Economic consideration tends to limit their use to small area overlays. Of the covered electrodes tested, the Codes D and F electrodes produced the most fissure-free deposits. Radiographic inspection of the Code D deposit revealed considerable porosity and the erratic deposition characteristic noted during the first layers was attributed to moisture in the electrode covering. An electrode bake at 400° F for 48 hr improved the usability characteristics and gave a very smooth arc. Porosity was still noticeable in the first portion of each bead, suggesting that additional baking would be required to completely remove

Fig. 15—Inconel (left) to A212 joint ($2^5/_8$ in.), welded with Code H filler metal (automatic inert-gas metal-arc). Heat-treated at 1150° F for 6 hr

Fig. 16—Inconel (right) to Inconel-clad A212, welded with Code H wire filler metal (automatic inert-gas metal-arc). Inconel-clad is Code H (automatic inert-gas metal-arc) deposit. Heat-treated at 1150° F for 4 hr. × $3^1/_2$ (Reduced by 65% on reproduction)

Table 9—Bend [a] Test Results of Overlay Test Weldments

	Longitudinal side bend	Transverse side bend	Transverse face bend
Code A electrode	(1) No defects (2) No defects	(1) 3 fissures	(1) Many semicontinous clusters (2) of fissures in both specimens
Code C electrode	(1) No defects (2) No defects	(1) 3 fissures (2) 1 fissure	(1) About 10 fissures (2) About 30 fissures
Code D electrode	(1) No defects (2) No defects	(1) No defects (2) 1 fissure	(1) No defects (2) No defects
Code F electrode	(1) No defects (2) No defects	(1) No defects (2) No defects	(1) No defects (2) No defects
Code H wire (auto. inert-gas, metal-arc)	(1) No defects	(1) 9 fissures	(1) Sample failed after 10 deg bend
	(2) 1 fissure	(2) Total failure of overlay after 100 deg bend	(2) No defects
Code H wire (auto. inert-gas, tungsten-arc)	(1) 3 fissures	(1) Unfused defects approx. 1/8 in. and 4 propagated fissures	(1) 1 fissure
	(2) 7 fissures and 1 unfused defect, 1 1/2 in.	(2) Unfused defects approx. 1/8 in. and 7 propagated fissures, 1 completely through clad	(2) 2 fissures
Code H wire (manual inert-gas, metal-arc)	(1) No defects (2) No defects	(1) 1 fissure (2) No defects	(1) 1 fissure (2) No defects

[a] All bend samples bent 180 deg unless otherwise stated.

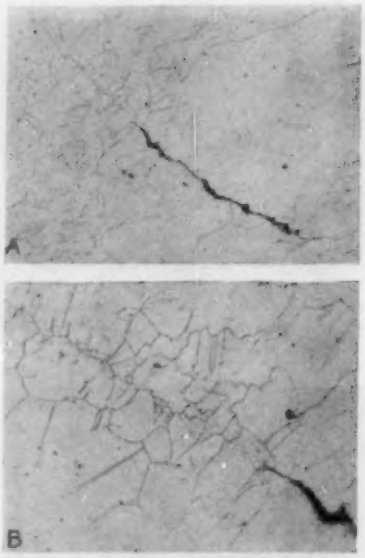

Fig. 19—Inconel base metal defect occurring in heavy section (2 3/8 in.) weld between Inconel and A212 steel, Code H wire filler metal (automatic inert-gas metal-arc). A—× 100; B—× 250. (Reduced by 65% on reproduction)

the dampness. The other covered electrodes used for overlay work in this program were sufficiently dry following lower temperature baking. As previously mentioned, storage history is a major factor in choice of baking time and temperature.

The results indicated that the Code F electrode produces the soundest weld overlay deposit of the electrodes tested. The level of fissuring in both the Codes A and C electrodes was higher than for the Code D electrode. Neither possessed usability characteristics or deposition rates sufficiently superior to warrant their recommendation for overlays.

The automatic inert-gas metal-arc process provided the highest deposition rate. Manual (semi-automatic) inert-gas metal-arc deposition rates are as high as those of the automatic inert-gas metal-arc process. However, lack of uniformity of thickness and surface finish requires considerably more machining. The automatic inert-gas tungsten-arc process of overlaying is the slowest of the inert-gas-shielded processes tested.

The Code H wire deposits made with automatic inert-gas-shielded arc processes showed a high hardness after exposure to postweld heat treatment. However, lower hardness values were exhibited by postweld heat-treated Code H wire overlays when deposited by the manual inert-gas metal-arc process. Accompanying this increase in hardness was a reduction in ductility. Transverse face and side bend tests from the hardened Code H wire automatic inert-gas metal-arc overlays showed a high number of fissures and failed by low ductility

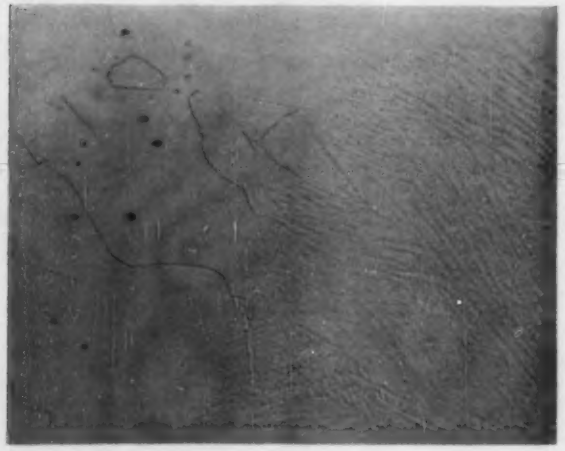

Fig. 17—Fusion zone of Inconel base metal to Code B electrode deposited weld metal. View illustrates sound base metal-weld metal interface. × 200 (Reduced by 25% on reproduction)

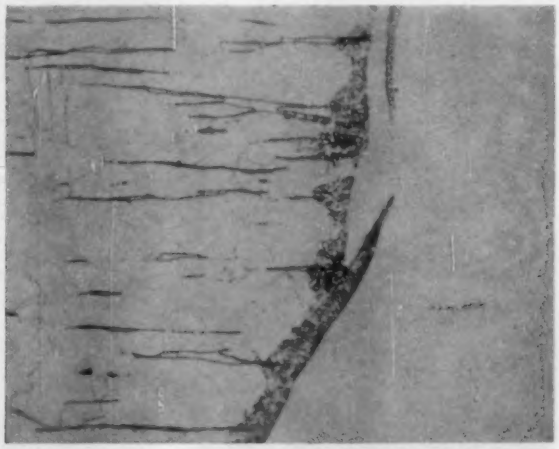

Fig. 18—Fusion zone of Type 304 base metal to Code C electrode deposited weld metal. View illustrates complex structure formed at dissimilar metal interface. × 200 (Reduced by 25% on reproduction)

Table 10—Summary of Deposit Analyses by Layer for All Overlays

Filler metal	Layer	Chemica composition, % C	S	Fe	Cr	Co	Cb+Ta	Mn	Si	Al	Ti	Ni	Mo
Code A electrode	1	0.056	0.010	25.78	12.22	0.083	1.75	1.06	0.46	0.030	0.087	59.30	...
	2	0.050	0.012	11.82	14.45	0.095	1.84	0.71	0.34	0.020	0.056	70.00	...
	3	0.055	0.010	8.07	14.72	0.090	2.14	1.18	0.43	0.035	0.087	71.60	...
Code C electrode	1	0.064	0.012	21.55	12.12	0.055	1.64	1.39	0.09	0.010	0.022	62.30	0.57
	2	0.047	0.007	11.03	14.70	0.045	1.93	1.46	0.10	0.005	0.025	68.80	0.64
	3	0.050	0.009	9.18	14.78	0.040	1.91	1.45	0.04	0.008	0.020	71.50	0.61
Code D electrode	1	0.135	0.005	17.30	14.78	0.065	2.98	0.48	0.13	0.060	0.085	63.20	...
	2	0.115	0.007	5.95	16.80	0.085	3.28	0.44	0.14	0.080	0.120	72.80	...
	3	0.105	0.009	4.38	17.13	0.060	3.33	0.49	0.11	0.060	0.095	73.40	...
Code F electrode	1	0.075	0.007	23.82	12.10	0.030	1.64	6.93	0.32	0.002	0.49	54.70	...
	2	0.056	0.010	12.60	13.80	0.040	1.84	6.97	0.15	0.005	0.43	64.00	...
	3	0.058	0.011	8.94	14.40	0.040	1.94	7.07	0.09	0.003	0.52	66.70	...
Code H wire (auto. inert-gas, metal-arc)	1	0.087	0.007	22.21	13.42	0.045	<0.01	1.82	0.13	0.040	2.46	59.50	...
	2	0.041	0.006	11.25	15.50	0.060	<0.01	2.06	0.14	0.060	2.75	67.30	...
	3	0.036	0.009	7.78	16.20	0.072	<0.01	2.06	0.13	0.065	3.62	71.00	...
Code H wire (auto. inert-gas, tungsten-arc)	1	0.033	0.007	15.08	14.78	0.080	0.03	2.11	0.07	0.040	3.06	64.60	...
	2	0.047	0.006	10.07	15.40	0.070	0.06	2.13	0.09	0.035	3.20	68.60	...
	3	0.042	0.006	7.48	15.55	0.070	0.01	2.17	0.12	0.037	3.27	71.20	...
Code H wire (manual inert-gas, metal-arc)	1	0.051	0.009	19.93	14.10	0.080	0.03	1.92	0.11	0.033	2.50	61.20	...
	2	0.042	0.008	8.94	15.50	0.090	0.02	2.09	0.17	0.030	3.41	69.50	...
	3	0.030	0.006	7.48	16.00	0.080	0.01	2.15	0.24	0.035	2.78	71.00	...

fracture of the cladding. The bend tests from the Code H wire, manual inert-gas metal-arc overlay exhibited satisfactory ductility properties in that there were no cracking failures.

Control of welding conditions may provide a means for controlling the hardening response and final ductility of Code H wire overlays. The compositions of the overlays deposited by the inert-gas-shielded processes were similar. The exact nature of the effect of the variation in welding conditions has not been determined. Either the rate of cooling or thermal fluctuations during cooling may affect the aging response. Evidently, this is associated with degree of supersaturation or the nucleation and particle size of the precipitating phase.

Since the bend test results from the Code H wire deposit were not similar (of two bends taken from the same overlay, one failed after approximately 10 deg bend, the other bent a full 180 deg, no failure), it is believed that fissures may be required to initiate cracking. The number and orientation of the fissures may be significant.

Corrosion tests made of representative sections of Inconel-weld overlay deposits appear to indicate that iron contents below about 15% do not seriously affect corrosion resistance to reactor plant water. In general, the Inconel-type filler metals exhibited corrosion rates comparable to those of the annealed Inconel base metal. The corrosion rates of overlay deposits increased with increase in iron content. However, these still were acceptable for up to about 15% iron. The corrosion data are not complete; it is probable that the corrosion test results will be reported at a later date.

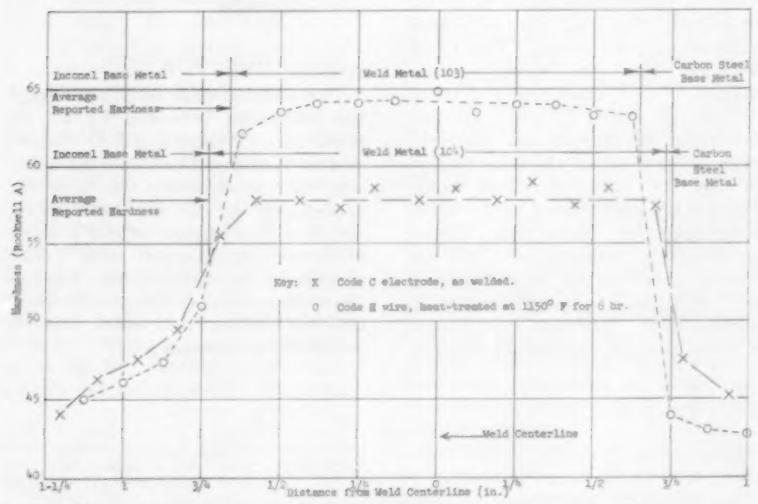
Inconel Base Metal
Weld Metal (103)
Carbon Steel Base Metal
Average Reported Hardness
Inconel Base Metal
Weld Metal (104)
Carbon Steel Base Metal
Average Reported Hardness
Hardness (Rockwell A)
Key: X Code C electrode, as welded.
O Code H wire, heat-treated at 1150° F for 6 hr.
Weld Centerline
Distance from Weld Centerline (in.)

Fig. 20—Hardness traverses of typical as-deposited and heat-treated welds

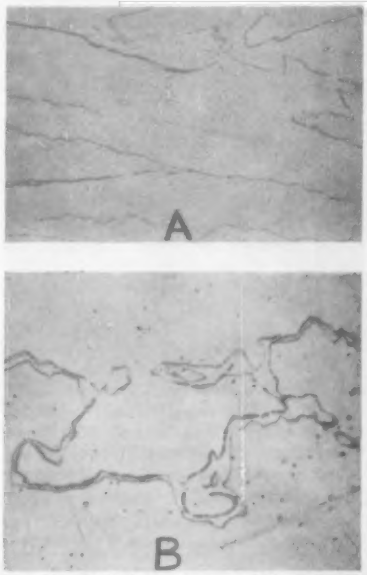

Fig. 21—Grain boundary constituent and microfissures in Code H wire deposit (automatic inert-gas metal-arc). Deposit heat-treated at 1150° F for 6 hr (A—× 250; B—× 1000) (Reduced by 65% on reproduction)

Fig. 22—Code H wire deposited on A212 steel by semiautomatic inert-gas metal-arc process. Heat-treated 4 hr at 1150° F. Section transverse to direction of welding. (Reduced 60% on reproduction)

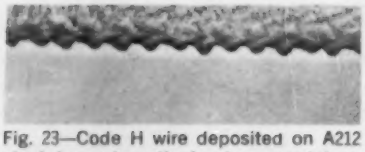

Fig. 23—Code H wire deposited on A212 steel by automatic inert-gas metal-arc process. Heat-treated 4 hr at 1150° F. Section transverse to direction of welding. (Reduced 60% on reproduction)

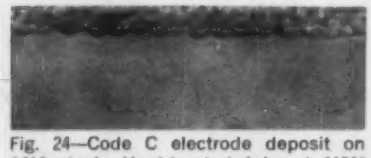

Fig. 24—Code C electrode deposit on A212 steel. Heat-treated 4 hr at 1150° F. Section transverse to direction of welding. × 1½ (Reduced 60% on reproduction)

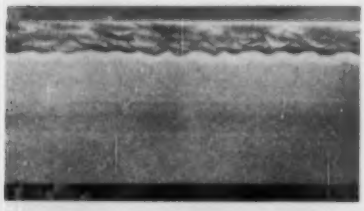

Fig. 25—Inconel weld overlay on A-212 carbon steel (three layers) with Code F electrode filler metal. Upper view—× 1.5; lower view—× 12; (Reduced by 55% on reproduction)

The Inconel-type bare wire filler metals for inert-gas-shielded arc welding produce relatively sound deposits. The inert-gas tungsten-arc weld deposits usually are free from porosity or fissures. However, the rate of weld-metal deposition with the manual inert-gas tungsten-arc process is the lowest of all applicable welding processes for Inconel welding. The automatic inert-gas tungsten-arc process work reported here has been limited to overlay deposits. In this area, the rate of deposition, although greater than that obtained manually, still is undesirably below those obtained by the covered electrode or the inert-gas metal-arc welding processes.

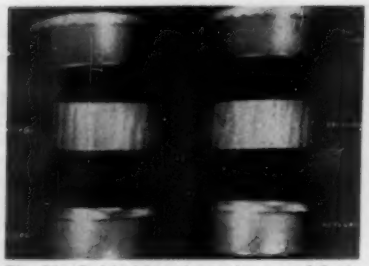

Fig. 26—Guided bend specimens of Code A electrode overlay on A212 steel. Heat-treated at 1150° F for 4 hr. Upper pair transverse side bend, center pair transverse face bend, lower pair longitudinal side bend

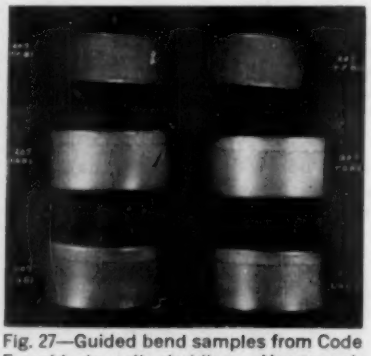

Fig. 27—Guided bend samples from Code F weld deposit cladding. Upper pair transverse face bend, center pair transverse side bend, lower pair longitudinal side bend

The inert-gas metal-arc process provides the highest rates of metal deposition required for extensive commercial production. The Code G wire, inert-gas metal-arc deposited, in moderately thick (1⅛ in.) to heavy (2⅝ in.) Inconel structural weldments are disposed to fissuring to about the same degree as the 300 series stainless steels. Fissures are undisclosed by the usual nondestructive inspection (liquid penetrant or radiographic), but are readily observed on side bends of weld sections, or on metallographic examination. However, the extent of these fissures has not, in general, exceeded the requirements of applicable welding procedure qualification codes or specifications. Porosity was not found to be a significant problem in inert-gas metal-arc welding with Code G wire provided adequate inert-gas coverage was maintained.

Fig. 28—Guided bend specimens of Code H wire overlay (automatic inert-gas metal-arc) deposited on A212 steel. Heat treated at 1150° F for 4 hr. Upper pair longitudinal side bend, center pair transverse face bend, lower pair transverse side bend

The stress-relief heat treatments required for associated plain-carbon or low-alloy ferritic steel components involve temperatures and heat-treatment times which will produce a significant hardness increase in Code H wire deposits. Although the hardened Code H wire deposit was not brittle in terms of the brittle fracture characteristics of ferritic steels, it still exhibited low notch toughness. The combination of fissures and high hardness resulted in extremely low tensile and bend ductilities for the hardened Code H wire deposits. Consequently, caution must be exercised in the use of this filler metal. Porosity in Code H wire, inert-gas metal-arc welded deposits has not been a problem.

Acknowledgments

The authors wish to acknowledge the assistance provided by D. B. Kittle, A. J. Palmer and J. D. Carey, of the Welding Development unit, and the sponsorship of this investigation by G. F. McKittrick and J. L. Van Ullen, of the Project Materials Application unit. The permission of the Atomic Energy Commission and of General Electric Co. to publish this work also is gratefully acknowledged.

Application of 2219 Aluminum Alloy to Missile Pressure-Vessel Fabrication

Details of the weldability, mechanical and metallurgical investigation of high-strength aluminum alloys are presented and discussed

BY CLAYTON H. CRANE AND WHITNEY G. SMITH

SYNOPSIS. The fabrication of a missile fuel tank from a high-strength aluminum alloy was desirable from the standpoint of design and production feasibility. The use of either 2014 or 2219 aluminum would provide an attractive weight saving over the lower strength 6061 alloy, but required considerable evaluation to determine the feasibility of using the copper-bearing alloys in fusion welded and heat-treated pressure vessels. The investigation showed that solution heat-treated and aged weldments of 2014 aluminum are inherently low in ductility and toughness, and are subject to premature failure under biaxial loads, while the 2219 alloy produces consistently a tough, ductile weldment when heat treated, and is well suited to pressure-vessel applications.

This paper describes the details of the weldability, mechanical and metallurgical investigation of these alloys.

Introduction

The use of an aluminum-alloy missile fuel tank resulted from many engineering and manufacturing considerations. The fuel tank is not only pressurized during flight, but is also a primary load-carrying structure having attachment points for the wings and powerplants. This loading dictated a complex design requiring that the tank be fabricated by welding a series of heavy ring forgings between cylindrical shell sections. A review of engineering materials was conducted to determine the alloy which would best fulfill the fuel-tank design requirements. This included strength-weight and stiffness-weight ratios at the service temperature, toughness, resistance to corrosion, ease of fabrication and cost of production. Of the various alloys considered, steel tanks were the heaviest because of the internal stiffening required by the cylindrical shells. A titanium alloy, Ti-6Al-4V, would result in a lightweight tank, but material costs were higher because of the large quantities of ring forgings required per tank. High-strength aluminum alloys could be utilized, with a slight weight increase, and the tanks could be produced at a minimum cost with existing equipment.

Three aluminum alloys—6061, 2014 and 2219—were found to best fulfill the design requirements and thereby warrant further consideration. The 6061 alloy had been used previously in a similar application and its mechanical and metallurgical properties were well established. A considerable weight-saving could be realized however by utilizing either of the higher strength 2014 or 2219 aluminum alloys. The 2014 alloy, though well established as a structural material, was generally regarded as unsatisfactory for applications requiring heat-treated weldments, but recent developments[1] in mechanized welding techniques had produced encouraging results. The 2219 aluminum alloy was a relative newcomer to the field and although it had not as yet achieved production usage, preliminary information[2] indicated that the alloy merited further consideration. A program was initiated to investigate the effects of welding process variables and postweld heat-treatment variables on the mechanical properties of 2014 and 2219 alloy weldments.

During the course of the investigation three types of specimens were used to determine weldment mechanical properties—(1) the tensile test for basic design allowable data, (2) the bend test as a measure of weldment ductility (3) and the burst-diaphragm disk to determine the toughness of a welded material under biaxial stress and hence its suitability for pressure-vessel applications. Simultaneously, a comprehensive metallurgical analysis was made of both 2014 and 2219 weldments to determine the effect of postweld heat treatment on their mechanical properties.

This paper will describe the details of the investigation and illustrate why the 2219 alloy was ultimately chosen for the missile fuel tank.

Base-metal Study

Metallurgical Characteristics

The first phase of the investigation consisted of a basic metallurgical consideration of the 2014 and 2219 alloy systems. The chemical composition limits of the two alloys are compared in Table I.

The 2014 alloy is of the aluminum-copper-magnesium-silicon type[3] employing copper aluminide ($CuAl_2$) as the primary precipitation-hardening agent. A secondary precipitation hardener, $CuMg_2Si_4Al_4$, greatly increases the strengths obtainable through artificial aging and is also responsible for the natural aging characteristics of this alloy.[4,5] Manganese is added to prevent formation of an undesirable Al-Cu-Fe-Si constituent and acts, to some extent, as a grain refiner. Titanium is allowed in limited amounts for its grain refining action. Iron, chromium and zinc are usually present as undesirable impurities.

The secondary 2014 aluminum alloying elments, magnesium and silicon, result in low-melting point ternary and quaternary eutectics which limit the solution treatment

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Table 1—Chemical Composition Limits

Element	2014 Min, %	2014 Max, %	2219 Max, %	2219 Min, %
Copper	3.9	5.0	5.8	6.8
Silicon	0.5	1.2	...	0.20
Iron	...	1.0	...	0.30
Manganese	0.40	1.2	0.20	0.40
Magnesium	0.20	0.80	...	0.02
Chromium	...	0.10	...	...
Zinc	...	0.25	...	0.10
Titanium	...	0.15	0.02	0.10
Vanadium	...	...	0.05	0.15
Zirconium	...	...	0.10	0.25
Others				
Each	...	0.05	...	0.05
Total	...	0.15	...	0.15
Aluminum	Remainder		Remainder	

temperatures to 925 to 945° F. The eutectic formed, their melting points and the resulting solution treatment temperatures of the 2014 and 2219 alloys are compared in Fig. 2. Complete re-solution of the $CuAl_2$ microconstituent cannot occur at the low solution temperature required for the 2014 alloy. Consequently, some residual $CuAl_2$ is always present in the microstructure. The distribution of this residual $CuAl_2$, as determined by the fabrication and heat-treatment history, greatly affects the ductility and toughness of the end product. The manner in which welding affects the distribution of residual $CuAl_2$, hence the ductility and toughness of the weldments, will be discussed later in this paper.

The 2219 alloy is a straight aluminum-copper alloy employing $CuAl_2$ as the sole precipitation hardener. Manganese is added to discourage the formation of undesirable eutectics and also for its grain refining action. Titanium, zirconium and vanadium are added as primary grain refiners, although some versions of this alloy use only titanium. Iron, silicon, zinc and particularly magnesium are impurities in the 2219 alloy and are held to extremely low limits.

The 2219 alloy differs from 2014 aluminum in that magnesium and silicon are not present as alloying elements. In the 2219 alloy, the elimination of these elements as alloying additions causes many changes in the characteristics of the alloy—low-melting point ternary and quaternary eutectics are eliminated, natural aging is reduced to an insignificant level, the strengths obtainable by artificial aging are reduced, and the cracking tendency of weldments is reduced. Solution treatment of 2219 aluminum may be carried out at temperatures just below the melting point of the primary Al-$CuAl_2$ eutectic (1018° F). Maximum re-solution of $CuAl_2$ takes place at the temperature range of 990 to 1010° F and excess $CuAl_2$ is rapidly agglomerated. This feature of the 2219 alloy is considered responsible for the excellent ductility and toughness exhibited by heat-treated weldments.

Heat-treat Characteristics

A solution-treatment temperature upper limit of 1010° F was selected for the 2219 alloy on the basis of alloy composition, eutectic-phase melting points and diffusion kinetics. A lower limit of 990° F was assigned to ensure maximum re-solution of soluble constituents and yet provide a practical temperature range for production heat-treat furnaces. Solution treatment times previously established for commercial copper-aluminum alloys were found to provide adequate re-solution of 2219 base metal soluble constituents without causing excessive grain growth and no departure from established practices was considered necessary. Weldments require a longer solution-treatment time than do the base metal and consideration must be given this fact in determining soaking periods for welded assemblies.

Various solution-treatment temperatures, time and quench temperatures were investigated in terms of their effect on mechanical properties, microstructure and corrosion resistance. These tests confirmed the earlier assumptions which had been based on chemical composition and past experience with copper-aluminum alloys. In addition, valuable information was gained regarding the types and distribution of microconstituents, grain size and diffusion mechanics as will be shown and described in detail later.

The selection of an aging cycle required that aging curves be established for conditions closely approximating those of the in-flight missile. The missile stress-temperature profile is unique and requires a specialized type of elevated temperature test to duplicate the flight conditions. This test requires that the specimen be heated to the test temperature in less than 30 sec, held at that temperature for periods ranging from 10 sec to 30 min and then rapidly loaded to cause failure in 3 to 10 sec. Aging curves were established under these conditions for aging temperatures from 350 to 420° F and for times up to 36 hr. An aging cycle of 12 hr at 350° F, designated T6E46, was found to provide the best design properties for this application. Tensile ultimate and yield properties for 2219-T6E46, 2014-T6 and 6061-T6 are compared in Figs. 3 and 4. These curves readily show that 2219 becomes increasingly competitive with 2014 at the higher design temperatures. Mechanical properties which are considerably superior to those characteristics of 2219-T6E46 material can be obtained by strain hardening solution-treated 2219 sheet prior to aging. These solution treated, cold worked and aged tempers were not included in this investigation since the fuel tank application requires heat treatment of the assembly following welding.

The ductility of 2219-T6E46 is excellent and averages over 16% elongation in a standard tensile test. Roll-forged rings exhibit typical elongations of 10% in the longitudinal direction, 8% in the long transverse and 5% in the short transverse directions. Toughness as indicated by notch-to-unnotched tensile-strength ratios, Kahn tear test, bend tests, and burst-diaphragm tests indicate that 2219 aluminum is the toughest of the heat-treated copper-aluminum alloys.

Corrosion Resistance

The high copper content of the 2219 alloy caused considerable concern regarding the corrosion resistance of the alloy, especially since a hot water quench was to be used. Base metal and welded 2219-T6E46 and 2014-T6 specimens were immersed in a mixture of JP-4 jet fuel and water for a period of 6 months. The specimens included unprotected, alodized and anodized surfaces. Examination after the 6-month immersion period revealed no serious pitting or intergranular corrosion. Corrosion tests of 2014-

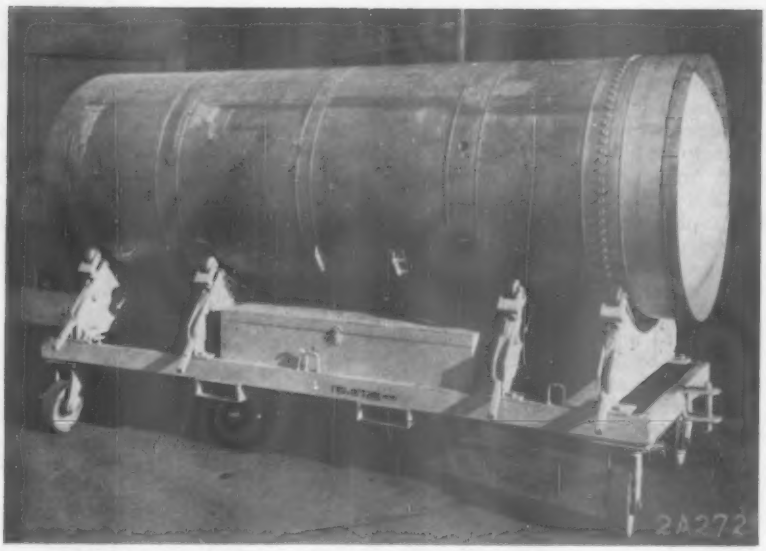

Fig. 1—Completed missile fuel tank fabricated from 2219 plate and forgings, and heat treated to the T6E46 condition

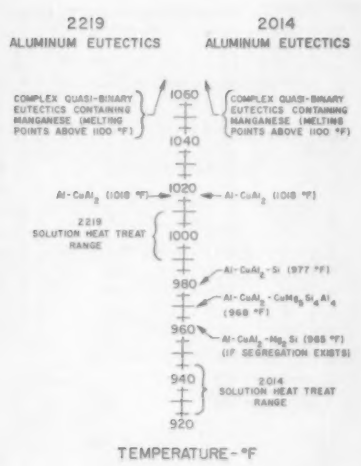

Fig. 2—A comparison of significant eutectics and their melting points for 2014 and 2219 aluminum alloys

T6 and 2219-T6E46 unprotected weldments in a standard hydrogen peroxide–sodium chloride solution[6] proved the two alloys to be comparable in corrosion resistance. Spot-welded specimens of 2014 bare to 2024 clad, and 2219 bare to 2219 bare, were solution treated and aged after welding and then subjected to a humidity-cycling temperature environment for 960 hr.[7]

The two alloys systems were found to be comparable in corrosion resistance and satisfactory for the fuel-tank application.

Experimental Procedure

Materials

Figure 1 illustrates a completed fuel tank welded from 2219 alloy and ready for pressure test. Each girth weld shown in the photograph represents the joining of a ring forging to a rolled plate shell, and the longitudinal welds indicate where the plate shells were joined. The forward tank-head assembly is joined to the tank mechanically to allow the installation of internal equipment after the tank is heat treated and artificially aged. The tank-wall thickness at the fusion weld varies from 0.100 to 0.250 in., with the 0.250 in. being the predominant gage.

Initial weld evaluation was performed on 0.250-in. thick plate to arrive at basic weld technique and material properties. Later in the program more detailed work was done by welding 0.250-in. thick plates to forgings as this represented one of the most critically loaded welds in the tank design. The forged strips used for the welding evaluation were obtained from a rolled-ring forging approximately 36-in. OD and having a 2-in. wall thickness. Strips were sawed from the periphery of the ring and then rolled flat. Later the strips were machined to a 0.250-in. thickness to match the plates. All welding was done with the material in the annealed condition, except for a limited amount which was done with 2014-T6 for testing in the as-welded condition.

Welding on the 2219 alloy was done with 2319 filler metal in both the mechanized butt welds and manual repair welding. A variety of weld filler metal was used on the 2014 alloy, with the most successful being 2014, 2319 and 4043. All three were tried in both mechanized butt welds and manual repair welding.

Welding

Mechanized welding was done by the direct-current straight-polarity (electrode negative) automatic gas-shielded tungsten-arc process, using helium gas for weld shielding. The weldments were made using a square-butt joint without a root opening. Filler wire of a 0.062 in. diam was used for mechanized welding, and repair welding was done with an a-c power source and 0.125-in. diam filler wire. A 2% thoriated-tungsten electrode having a 0.125 in. diam was used for the welding. Panels as shown in Fig. 5 were welded in a horizontal stake welding fixture having steel hold-down fingers and a stainless-steel backing bar with a 0.05-in. deep

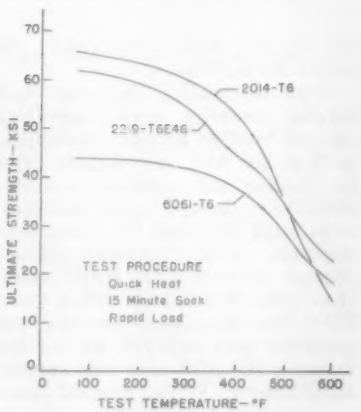

Fig. 3—Effect of temperature on the ultimate strength of various aluminum alloys. The data are typical for 0.250-in. thick transverse plate specimens

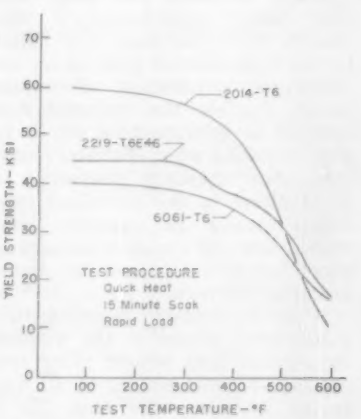

Fig. 4—Effect of temperature on the yield strength of various aluminum alloys. The data are typical for 0.250-in. thick transverse plate specimens

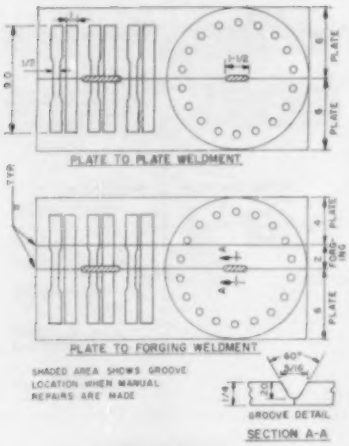
PLATE TO PLATE WELDMENT
PLATE TO FORGING WELDMENT
SHADED AREA SHOWS GROOVE LOCATION WHEN MANUAL REPAIRS ARE MADE
GROOVE DETAIL
SECTION A-A

Fig. 5—Drawings of weldments used in evaluating 2014 and 2219 show the layout of repair grooves and specimen dimensions

by 0.50-in. wide oval groove to retain the back bead.

Prior to welding, the plate and forging material were chemically cleaned using a chromic-sulfuric acid pickle, and immediately prior to welding the material was mechanically cleaned using stainless-steel wool to brush the weld area surfaces. If butting edges did not appear smooth (125 RMS max), they were filed lightly with a vixen file. The mechanical cleaning was preceded and followed by solvent cleaning the joint area with methyl ethyl ketone. While chemical cleaning was found not to be necessary (providing thorough mechanical cleaning was used), it was used primarily on new material to remove bright mill oxide and foreign material and thus make mechanical cleaning an easier and faster job. The heavy grain-boundary precipitate of copper-aluminide found in the heat-affected zone of all as-welded copper-bearing aluminum alloys, renders the material susceptible to intergranular attack in that condition when chemical cleaning. Any chemical processing of these alloys in the as-welded condition should be carefully controlled to avoid excessive immersion time which may lead to intergranular corrosion.

After mechanical cleaning, the plates were placed in the welding fixture and butt welded using two passes. A weld setting of 10 ipm travel, 30 ipm wire feed, 12 v arc voltage and about 275 amp were used on the first pass; and 10 ipm travel, 30 ipm wire feed, 13½ v arc voltage and 225 amp were used on the second pass. The first pass was made with complete penetration and the second pass was used to fill the joint and form a 0.03-in. high top bead. The higher voltage was required on the second pass to spread the bead slightly and prevent undercut. Successful welds were made on 0.250-in. thick plate using a single pass, but an occasional gas hole or oxide inclusion would result. The single pass required a wire feed of 60 ipm; it is believed that this amount of wire in one pass causes gas or oxides to be trapped in the solidifying weld metal. This was found to be particularly true with 2014 alloy. The 2219 alloy was easier to weld than the 2014 alloy due to the manner in which the filler metal flowed into the joint and formed a smooth low-contoured top bead. However, a double pass technique was required in production to keep defects to a minimum.

Manual Welding

The fuel tank shown in Fig. 1 contains over 1000 lin in. of weld and requires 18 separate production setups, all of which make it virtually impossible to weld without creating some defects that require a manual repair. Since any type of manual repair is inferior to the original weld, a large part of the weld-evaluation program was concerned with repair techniques and repair strength and ductility. In tank production, the type of defects in 0.250-in. plate that require repair are gas holes greater than one-third the plate thickness, inclusions greater than 0.08 in. in length or having cracklike appearance, any crack, and small porosity or gas holes that align themselves to form a continuous band more than 0.08 in. in length. When defects like these were found they were removed by grinding and the resulting groove thoroughly cleaned and filled by manual welding.

In the repair-welding evaluation, panels were taken that had been butt welded with the two-pass method as explained previously, and were grooved and manually repaired as shown in Fig. 5. In actual production, the size of the repair weld may be quite large compared to the original defect, due to the relatively large groove that is required when the defect is deep. Early work in the program showed that an increasing repair-weld size resulted in decreasing tensile strength and elongation; therefore all repair-weld evaluation was made by manually filling the largest grooves expected in production.

The 2219 alloy repaired very easily with 2319 filler wire, showing little tendency to crack. The 2014 alloy was difficult to repair due to cracking which occurred in the repaired weld metal, or more often in the heat-affected zone of the base metal. Of the three filler metals used on 2014 alloy, the 4043 filler metal gave the least cracking and the 2014 and 2319 filler metals the most cracking.

Physical Testing

Specimen Preparation

Welded panels were cut into the types of specimens shown in Fig. 5. Metallurgical specimens were cut from each panel for investigation in the as-welded and heat-treated condition.

Tensile and bend specimens were cut and machined to the dimensions shown, and both had the weld beads removed by milling followed with a light belt sanding over the gage length to remove any surface defects. The tensile specimen was used for obtaining strength data from both the automatic and manual repair-welded specimens. The bend test was used because of its ability to measure elongation in the weld area. It is more sensitive for measuring effect of many of the welding variables than is the tensile test.

Burst-diaphragm disks were machined to fit the test fixture shown in Fig. 6. The weld beads were removed flush from both sides of the disk for a distance of about 3 in. in from each end of the weld. This was necessary for the "O"-ring seal and to eliminate interference when clamping the disk in the fixture. The weld beads were left on (0.03 in. max height) for the center 6 in. of the weld as this was the actual pressure-vessel operating condition.

The burst diaphragm was used in this program because the materials were being evaluated primarily for

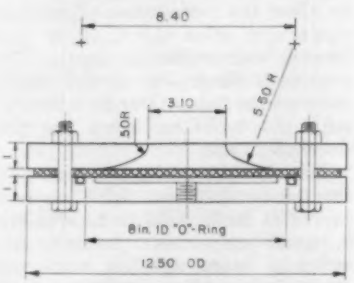

Fig. 6—Cross section of burst-diaphragm test fixture showing general configuration and dimensions

Table 2—Tensile-test Result Summary

Total no. spec.	Base-metal alloy	Type[a] weld joint	Weld filler wire	Repair filler wire	Post-weld HT	Tensile strength, avg ksi	Yield strength, avg ksi	Elongation, % in 2 in. Max	Min	Avg
27	2219-0	Pl-Pl	2319	None	T6E46	65.5	46.2	16.0	8.0	12.5
12	2219-0	Pl-Pl	2319	2319	T6E46	58.8	45.5	8.7	2.0	5.0
24	2219-0	Pl-Fg	2319	None	T6E46	59.2	44.1	9.5	3.0	7.0
12	2219-0	Pl-Fg	2319	2319	T6E46	56.9	44.3	6.7	2.0	5.0
32	2014-0	Pl-Pl	2014	None	T6	68.9	61.8	11.0	1.0	5.5
10	2014-0	Pl-Pl	2319	None	T6	69.7	62.5	9.0	1.0	5.0
9	2014-0	Pl-Pl	4043	None	T6	65.8	60.0	3.0	2.0	2.5
10	2014-0	Pl-Pl	2014	None	T4	62.1	37.5	15.0	8.0	12.0
14	2014-T6	Pl-Pl	2319	None	None	43.6	27.7	6.0	3.0	5.0
12	2014-0	Pl-Pl	2319	2319	T6	48.9	46.4	2.0	0.0	1.5
12	2014-0	Pl-Pl	2014	2014	T6	45.1	[b]	2.0	0.0	1.0
9	2014-0	Pl-Pl	4043	4043	T6	28.3	21.2	4.0	2.0	3.0
15	2014-0	Pl-Fg	2319	None	T6	55.6	[b]	6.0	0.0	1.5
	Base-metal data									
15	2219-T6E46 (transverse plate)					67.5	46.5	19.0	14.0	16.0
15	2219-T6E46 (forging-short transverse)					59.0	48.2	6.0	4.0	5.0
9	2014-T6 (transverse plate)					71.5	65.2	13.0	5.0	9.0
15	2014-T6 (forging-short transverse)					66.9	60.9	8.0	2.0	4.5

[a] Pl-Pl = Plate-to-plate welds. Pl-Fg = Plate-to-forging welds.
[b] Specimens usually broke without apparent yield point.

Table 3—Bend-test Result Summary

Total[a] no. spec.	Base-metal alloy	Type[b] weld joint	Weld filler metal	Repair filler metal	Post-weld HT	Bend radius, in.	Bend angle, deg Max	Min	Avg
18	2219-0	Pl-Pl	2319	None	T6E46	5T	60	40	58
18	2219-0	Pl-Pl	2319	2319	T6E46	5T	60	16	26
32	2219-0	Pl-Fg	2319	None	T6E46	5T	60	19	34
16	2219-0	Pl-Fg	2319	2319	T6E46	5T	47	15	23
36	2014-0	Pl-Pl	2014	None	T6	5T	60	3	12
20	2014-0	Pl-Pl	2319	None	T6	5T	42	3	14
12	2014-0	Pl-Pl	4034	None	T6	5T	49	9	18
9	2014-0	Pl-Pl	2014	None	T4	5T	60	60	60
12	2014-T6	Pl-Pl	2319	None	None	5T	41	16	23
15	2014-0	Pl-Pl	2014	2014	T6	5T	13	0	5
11	2014-0	Pl-Pl	2319	2319	T6	5T	24	5	14
12	2014-0	Pl-Pl	4043	4043	T6	5T	55	6	31
12	2014-0	Pl-Fg	2014	None	T6	5T	11	0	6

[a] Each set of bend specimens contains approximate equal numbers of root and face-bend specimens. Bend angle was not appreciably different for the two types.
[b] Pl-Pl = Plate-to-plate welds. Pl-Fg = Plate-to-forging welds.

Table 4—Burst-diaphragm-test Result Summary

Total no. spec.	Base-metal alloy	Type[a] weld joint	Weld filler wire	Repair filler wire	Post-weld HT	Test pressure Max, psi	Min, psi	Avg, psi	Bulge height Max, in.	Min, in.	Avg, in.
5	2219-0	Pl-Pl	2319	None	T6E46	4000	4000	4000	0.56	0.56	0.56
10	2219-0	Pl-Fg	2319	None	T6E46	4000	1400	3290	0.56	0.37	0 52
7	2219-0	Pl-Fg	2319	2319	T6E46	4000	850	1850	0.56	0.20	0.37
3	2014-T6	None	None	...	...	4000	4000	4000	0.53	0.53	0.53
12	2014-0	Pl-Pl	2014	None	T6	3150	750	1390	0.50	0.12	0.31
3	2014-0	Pl-Pl	2014	None	T4	4000	3200	3730	0.62	0.62	0.62
2	2014-0	Pl-Pl	4043	None	T6	2800	2700	2750	0.53	0.50	0.51
12	2014-0	Pl-Pl	2319	None	T6	3850	1250	2530	0.56	0.31	0.50
5	2014-0	Pl-Pl	2319	None	T4	4000	2500	3560	0.62	0.47	0.58
6	2014-T6	Pl-Pl	2319	None	None	2250	1450	2030	0.56	0.38	0.50
4	2014-0	Pl-Pl	2319	2319	T6	650	350	510	0.06	0.03	0.05
3	2014-0	Pl-Pl	2319	2014	T6	600	480	500	0.06	0.03	0.05
3	2014-0	Pl-Pl	2319	4043	T6	750	480	610	0.10	0.08	0.09
3 (1)	2014-0	Pl-Fg	2319	None	T6	650	250	450	0.03	0.03	0.03
5 (2)	2014-0	Pl-Fg	2319	None	T6	2300	400	161[b]	0.50	0.03	0.22
5 (2)	2014-T6	Pl-Fg	2319	None	None	2000	1350	1710	0.50	0.37	0.47

[a] Pl-Pl = Plate-to-plate welds. Pl-Fg = Plate-to-forging welds. (1) Coarse-grained forgings. (2) Fine-grained forgings.

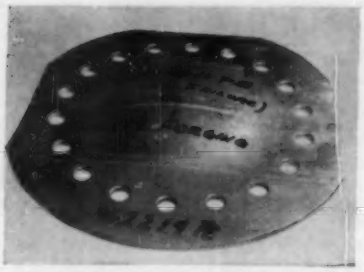

Fig. 7—Burst-diaphragm specimen after test. Typical of 2219-T6E46 plate-to-forging weldments

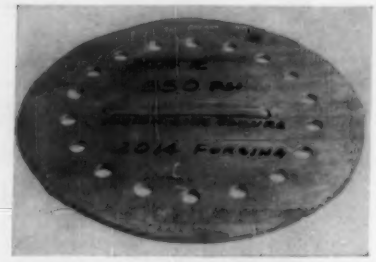

Fig. 8—Burst-diaphragm specimen after test. Typical of 2014-T6 plate-to-forging weldments

use in pressure-vessel application.[5] The diaphragm produced biaxial stresses, and also allowed the testing of a relatively large weldment under what might be considered as actual operating conditions. The test was particularly useful in determining the effect of repair welds on a large weldment as to strength and its ability to transmit load to an unrepaired area.

Specimen Testing

After machining, all specimens were solution heat treated and aged: the 2014 to the T6 condition and the 2219 to the T6E46 condition. The specimens were given a 150° F water quench to correspond to the production fuel-tank quench.

Tensile specimens were tested and data recorded as shown in Table 2. Data in Tables 2, 3 and 4 only include specimens without defects. Specimens with defects were also tested and their results used separately to establish X-ray inspection standards.

Bend specimens were tested with the direction of the weld parallel with the ram. For 0.250-in. thick plate, a ram was used having a $1^1/_4$ in. radius (5T) and the specimens were bent until a 60-deg angle or failure occurred. Early work showed that a 60-deg bend angle is adequate since nearly all specimens that fail do so in less than 50 deg. When averaging the bend angles, the 60-deg max does not cause an exceptionally good specimen to overweight the averages.

The burst-diaphragm disk was tested by clamping the disk tightly in a fixture and applying water pressure from the bottom, thus causing the disk to bulge upward against a top retaining ring. Water pressure was applied until 4000 psi gage pressure or failure occurred. After the test was stopped and water pressure was released, the height of the permanent set (bulge) was measured and recorded along with the maximum pressure reading.

Test Results

Development work was done on several material thicknesses, the majority being on 0.250-in. plate; and these results are shown in Tables 2 to 4, inclusively. The results shown in the tables represent a portion of the data collected and are considered by the authors to be typical of the entire program. It must be kept in mind that the data in the tables include many different heats of plate and forging and probably many small variations of welding technique and heat treat-response.

Tensile Tests

The results in Table 2 show that 2219-T6E46 plate and forging weldments produce consistent strength properties and with good elongation. The drop in tensile strength and elongation of plate-to-forging specimens is usually associated with the less favorable grain orientation in the forging. The unrepaired 2014-T6 plate-to-plate weldments gave consistently high tensile strengths, but with low and erratic elongation. Specimens from 2014-T6 plate-to-forging weldments were completely lacking in any consistent tensile-property pattern, and often failed without a measurable yield point.

Repaired welds in 2219-T6E46 showed some loss in strength and elongation, but still retained the type of consistency required for confidence. The 2014-T6 alloy when repaired with 2014 and 2319 filler wires gave highly erratic results, but gave reasonable consistency when repaired with 4043 filler wire. Although 4043 filler wire will not respond to heat treat to give a high tensile strength, the opinion of the authors is that 4043 is the easiest filler wire to use and gives the best degree of confidence for manual repairing the 2014 aluminum alloy.

Bend Tests

The minimum bend angle required for the aluminum weldments to be considered satisfactory for pressure-vessel service is not known. Since a bend angle of approximately 25 deg is required to form the weld and heat-affected zone around a 5T radius, this angle was considered the minimum average acceptable when evaluating welded alloys. The bend-test results in Table 3 illustrate the marked superiority of 2219 over 2014 in welded bend ductility. The 2014 alloy shows promising characteristics at times but in the end it must be categorized as erratic in bend ductility. The results of the bend tests on repaired welds must be carefully analyzed due to the heat-treat response of the filler wire. The 2219 repaired specimens formed around the ram radius until failure occurred, thus giving a true measure of ductility in the heat-affected zone. However, the 2014 alloy when repaired with 2319 or 4043 filler alloys were low in strength and would not form around the ram radius but would be lifted away from the ram by action of the rigid base metal. This caused all bend to take place in the repair metal and made the actual radius of the bend approach zero. The test still has merit for repaired welds since it determines if the weld itself will offer some elongation and thus be able to redistribute stresses in a biaxially stressed condition.

Burst-diaphragm Tests

From the start of the weld-evaluation program, 2014 weldments were known to lack ductility; however, the minimum ductility required in a pressure-vessel weldment was not known. To help answer this question, the burst-diaphragm disk was used in the evaluation as a method to test larger weldments under simulated operating conditions, and also as a small pressure-vessel test in itself. The burst diaphragm was used as a comparative test in this program. The actual pressure reading obtained is not important by itself but must be related to the material's heat-treat condition, and then correlated with the deflection (bulge height). Strain-gage readings showed that approximately 0.25-in. bulge height is required before a yield point corresponding to 0.2% offset has occurred. In judging the results, diaphragms with less than 0.25-in. bulge height were considered marginal or inadequate.

The test results were startling at times and clearly defined the effect of elongation and repair welding on pressure-vessel re-

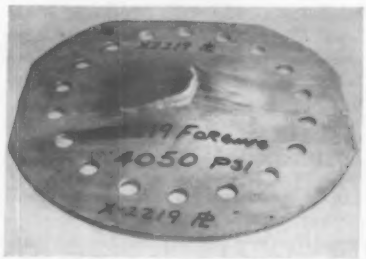

Fig. 9—Burst diaphragm of 2219-T6E46 plate-to-forging weldment. This specimen had been manually repaired and shows the exceptional ability of the alloy to be repaired

liability. The 2219 alloy performed well in all combinations of plate, forging and repair welding. The 2014 alloy looked promising only when used in the plate-to-plate combination without repair welds. Figures 7 and 8 show typical 2219 plate-to-forging and 2014 plate-to-forging burst diaphragms, respectively. The 2219 alloy always showed considerable elongation (bulging) before failing, and the 2014 alloy seldom offered any elongation in the plate-to-forging combination, and failed in the same manner as did the full-scale 2014 tanks during burst test. Figure 9 shows the exceptional properties of 2219 alloy in the repaired condition.

Metallurgical Analysis

2014 Alloy Weldments

Tables 2 through 4 show that heat-treated 2014 alloy plate-to-plate weldments (unrepaired) generally exhibit good strength and ductility as determined by tensile, bend and burst-diaphragm tests. Too frequently however, these weldments are characterized by good tensile and yield strengths, but show almost no ductility or toughness. Heat-treated and aged 2014 alloy plate-to-plate weldments must therefore be considered as being erratic in behavior. Plate-to-forging, heat-treated and aged weldments seldom exhibit any ductility, and both tensile and burst-diaphragm tests are characterized by brittle, premature failures.

Fracture of plate-to-forging weldments occurred predominantly in the heat-affected zone of the forging. Metallographic examination revealed that the fractures occurred intergranularly at a point 3 to 5 grain widths away from the weld-fusion line. An examination of a typical failure shown in Fig. 10, shows the forging grains adversely oriented so the service loads are applied across the short transverse grain direction of the forging. The grain size is larger than desired although typical of 2014 forgings.

The most significant fact is the presence of a continuous brittle grain-boundary network of $CuAl_2$ bordering the fracture and completely encompassing the adjacent grains. This condition is evident in Fig. 11. The welding process has caused the material in the heat-affected zone to be rapidly heated to a very high temperature for a short period of time and then cooled slowly to room temperature. The material does not remain at the high temperatures long enough to result in incipient melting of the ternary and quaternary eutectics, but during the slow-cooling process large quantities of copper aluminide ($CuAl_2$) are precipitated in a continuous network at the grain boundaries. The quantity of $CuAl_2$ precipitated at any given point on a grain boundary is a function of the grain surface-to-mass ratio at that point; thus the grain surfaces which are normal to the short transverse grain direction are the most severely affected.

This continuous $CuAl_2$ network must be broken up by re-solution or agglomeration at the solution-treatment temperature, if ductility and toughness are to be realized in the heat-treated weldment. Unfortunately, the permissible solution-treatment temperature of the 2014 alloy is lowered by the presence of the secondary alloying elements and neither adequate re-solution nor agglomeration can take place. Laboratory efforts to redissolve the $CuAl_2$ network at the standard solution-treatment temperature of 925 to 945° F for periods of time up to 60 hr were unsuccessful. Solution treatments at higher temperatures and for shorter times were more successful, but resulted in excessive incipient melting and formation of gaseous porosity by the time the desired microstructure was achieved.

The effect of this brittle and continuous grain-boundary network was found to be largely a function of the matrix hardness. Its presence has little or no effect on the properties of as-welded or solution-treated weldments (see Tables 2, 3 and 4), but drastically reduce the strength, ductility and toughness of solution treated and artificially aged weldments. Apparently the soft and ductile matrix of as-welded or solution-treated material is more capable of redistributing stresses than is the matrix of the artificially aged material. Fine-grained forgings with favorable grain orientation

Fig 10.—A typical brittle fracture in a 2014-T6 alloy plate-to-forging weldment. The adverse grain size and orientation in the forging contributed to the brittle behavior. Keller's etch. × 10. (Reduced by 25% upon reproduction)

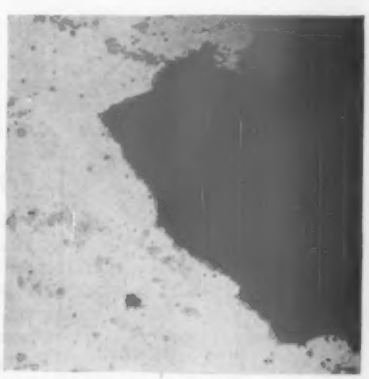

Fig. 11—A portion of the fracture seen in Fig. 10 is shown with greater magnification. Primary cause of the failure was the brittle grain-boundary precipitate ($CuAl_2$) caused by the heat of fusion welding. Unetched. × 500. (Reduced by one-half upon reproduction)

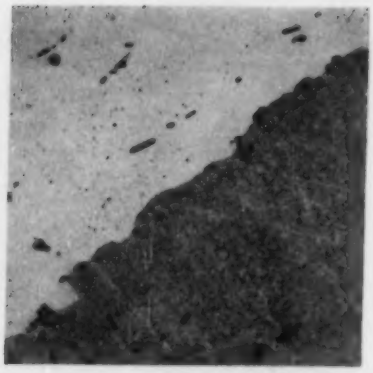

Fig. 12—The heat-affected zone on the forging side of a 2219-T6E46 plate-to-forging weldment. The solution heat treatment has adequately dissolved and agglomerated the $CuAl_2$ constituent. Keller's etch. ×750. (Reduced by one-third upon reproduction)

were obtained for fabricating burst-diaphragm specimens. Tests results indicated considerable improvement, and properties approaching those of plate-to-plate weldments were occasionally obtained.

The erratic behavior inherent in heat-treated 2014 alloy weldments may well be the result of insufficient re-solution and agglomeration of the $CuAl_2$ network. Conclusive proof, however, will require further investigation.

2219 Alloy

Metallographic examination of re-solution treated 2219 alloy plate-to-forging weldments proved the advantages of the higher solution-treatment temperature. The continuous grain-boundary precipitate has been eliminated by re-solution and agglomeration. Figure 12 illustrates the typical microstructure found in the heat-affected zone of the 2219 forging after re-solution treatment.

Tensile, bend and burst-diaphragm tests performed on 2219 alloy plate-to-plate and plate-to-forging weldments in the T6E46 condition were characterized by consistent strength, ductility and toughness. Although the original 2219 forgings used in the tests contained extremely large grains and adverse grain orientation, there was no adverse effect on the physical properties of the weldment. Multiple-pass welding and manual repairs also had little effect on the physical properties, thereby demonstrating the excellent ability of the alloy to tolerate welding discrepancies.

Conclusions

The results of the investigation may be summarized as follows:

1. The test results show that fusion-welded 2014 aluminum alloy should only be used in the as-welded or naturally aged conditions.

2. The 2014 alloy, welded and heat treated cannot be manually repaired in a manner to produce welds with high strength and consistent quality.

3. Fusion welded 2014 alloy, heat treated to the T6 condition after welding, will produce unsatisfactory reliability for applications requiring high strength under biaxial loads.

4. The 2219 aluminum alloy is weldable and will produce heat-treated and aged welds with consistent strength and adequate ductility, and is suitable for pressure-vessel application.

5. The 2219 alloy is readily repaired in any combination of plate-and-forging welded joints, and produces repaired welds with good strength and consistency.

6. Production experience to date indicates the welding characteristics of the 2219 alloy are as good or better than those of 6061 aluminum alloy.

7. Alloy 2219 should be given serious consideration for any fusion-welded aluminum part that requires heat treatment and aging after welding.

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WRC Bulletin No. 65

Feasibility Studies of Stresses in Ligaments

This Bulletin, published in November 1960, is the final report of Southwest Research Institute on a research program carried out for the PVRC Subcommittee on Stresses in Ligaments. The object of the program was to study four different experimental techniques to ascertain which technique is best suited for a comprehensive test program for the analysis of stresses in ligaments. The four experimental techniques used in this study were: (a) Photostress; (b) bonded electric strain gages; (c) photoelasticity (three-dimensional); and (d) Stresscoat. The report describes the results of tests with each of the four techniques and, on the basis of the results of these tests and cost considerations, makes recommendations as to which technique is most efficient.

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Brittle Fracture Characteristics of A Reactor Pressure-Vessel Steel

For test conditions used, A302B steel proves more brittle-fracture resistant than other steels in paper sponsored by ASME

BY E. T. WESSEL AND W. H. PRYLE

ABSTRACT. The brittle fracture characteristics of Type ASTM A302B steel were determined with material from a 7-in. thick plate for both the as-received (normalized) condition and after a heat treatment consistent with the thermal cycles encountered during the fabrication of a reactor pressure vessel. The heat-treated steel was found to be slightly more notch sensitive and had a somewhat higher transition temperature than the as-received steel. In comparison with other steels that have been studied under similar conditions, the A302B steel was found to be considerably more brittle-fracture resistant. For the particular test conditions used, average applied stresses in excess of the normally measured yield strength were required to cause fracture in the A302B steel even in the presence of a pre-existing large crack at temperatures above −150° F. Other steels tested similarly, fractured at a fraction of the yield strength at much higher temperatures.

Introduction

Reactors of the pressurized water type employ thick-walled pressure vessels made of a manganese-molybdenum steel with a relatively thin stainless-steel cladding. As is true for nearly all applications involving large heavy sections of ferritic materials, consideration must be given to the brittle failure potential. To prevent the possibility of any brittle fracture, it is necessary to specify certain design and operational limitations. Naturally, in these considerations it is desirable to provide positive assurance against brittle failure without excessive conservatism and, at the same time, make maximum utilization of the strength of the steel. For these purposes it is essential to have a comprehensive knowledge of the brittle fracture characteristics of the steel that is used. This paper describes a portion of some experimental work on brittle fracture that has been conducted using a typical reactor pressure-vessel steel.

As part of a general study of brittle fracture a new technique for measuring fracture susceptibility was employed.[1, 2] This technique utilizes relatively large, flat tensile specimens containing pre-existing sharp cracks. Cracks and crack-like defects are possible in large steel sections and structures in the form of weld cracks, forging cracks, inclusions, voids, segregation of hard phases, etc. When the large pre-cracked specimens are tested over a range of temperatures, they describe the ductile-to-brittle transition behavior in terms of the average applied stresses and strains that are required for fracture. This provides a picture of the brittle transition phenomena in terms of the factors commonly used in design. In some other steels that have been investigated, a sharp transition in the fracture strength from well above to well below the conventionally measured yield strength occurred over a narrow temperature range.

The present paper describes the results of similar tests that were conducted with a specific plate of ASTM, A302, Grade B steel in both the "as-received" condition and after a heat treatment which duplicated the thermal cycles that are encountered during fabrication of a pressure vessel. The crack-notch tensile experiments are supplemented with conventional plain and notched tensile data as well as the commonly used types of impact toughness tests.

Material

All steel used in this investigation came from a large, 7-in. thick plate of Type A302B steel. The chemical analysis was as follows:

C	0.21 %
Mn	1.34 %
P	0.015 %
S	0.010 %
Si	0.27 %
Ni	0.04 %
Cr	0.09 %
Mo	0.50 %
Cu	0.08 %

The plate had been normalized and tempered by the supplier and one phase of the study used the steel in this, the "as-received," condition. Normalize usually denotes cooling in still air; however, in this class of material suppliers often use a water spray or mist to accelerate cooling. This particular plate was spray-cooled during the normalizing treatment. The second phase of the study used material from the same plate, but it was subsequently heat treated as follows:

1. Held 4 hr at 2275° F and furnace cooled at 30° F per hour to 400° F, then air cooled to room temperature (to simulate cladding operation).

2. Heated to 1650° F and held for 7 hr, then cooled in still air to room temperature (renormalized after cladding).

3. Heated to 1150° F, held 7 hr, then air cooled to room temperature. This step was repeated 5 times (stress relief treatments after welding). This heat treatment was intended to duplicate the thermal conditions that are encountered during

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Table 1—Crack-notched Tensile Properties of Type A302B Steel Plate Specimen as per Fig. 2.

Specimen	Temp., °F	Thickness "t", in.	Width "L," in.	Crack length "c," in.	Net section fracture strength σ_N, 1000 psi	Gross section fracture strength 1000 psi	Reduction in thickness, % Local	Reduction in thickness, % Average	Fracture toughness Gc, lb/in.	Relative thickness, α	c/L	Brittle fracture, %	Fracture type
As-received condition													
A302B-1-CN5	—300	0.625	4.16	0.90	76	48.0	1.0	0.3	278	0.84	0.216	100	c[b], flat
B-2-CN2	—200	0.625	3.46	1.09	82	30.0	0.5	0.5	162	0.93	0.316	100	c, flat
B-1-CN9	—100	0.626	4.92	1.00	74	45.5	6.3	2.4	285	0.29	0.204	99	s>c[c], flat
B-2-CN3	—60	0.625	3.35	1.12	82	28.7	5.1	4.6	168	0.50	0.334	99	s>c, flat
B-1-CN2	—27	0.501	4.73	1.00	73	42.0	6.6	3.2	264	0.23	0.212	97	s>c, flat
B-1-CN4	0	0.626	4.21	1.20	80	39.4	12.9	8.3	294	0.22	0.285	95	s>c, flat
B-1-CN8	50	0.627	4.08	1.06	81	41.1	12.1	5.8	268	0.21	0.260	95	s>c, flat
B-2-CN1	80	0.624	4.11	1.17	79	33.6	18.8	22.9	210	0.24	0.285	0	s[d], 45°
B-1-CN1	80	0.624	4.45	1.07	75	39.0	19.4	25.0	228	0.22	0.240	0	s, 45°
B-1-CN3[a]	80	0.245	5.18	0.98	70	46.4	16.0	45.0	254	0.07	0.190	0	s, 45°
B-1-CN6[a]	80	0.244	4.08	0.98	78	38.8	18.4	43.0	216	0.09	0.240	0	s, 45°
B-1-CN12[a]	80	0.250	4.63	1.04	76	41.4	19.6	41.0	255	0.07	0.225	0	s, 45°
B-1-CN11	300	0.627	4.17	1.05	70	34.0	18.6	34.0	191	0.15	0.250	0	s, 45°
B-1-CN10[a]	500	0.409	4.34	1.16	68	31.6	14.5	30.0	159	0.11	0.270	0	s, 45°
As heat-treated condition													
A302B-HCN-111	—320	0.625	5.08	0.96	39	24.4	0.0	0.0	76	4.6	0.189	100	c, flat
-106	—200	0.622	4.66	0.93	74	41.7	0.3	0.3	221	0.68	0.200	100	c, flat
-113	—100	0.624	3.57	0.98	74	30.2	1.6	2.3	137	0.75	0.274	99	c, flat
-107	—50	0.621	4.89	0.81	72	45.8	5.3	2.7	286	0.30	0.203	98	s>c, flat
-109	0	0.624	4.86	0.89	72	45.5	10.2	3.1	210	0.38	0.160	95	s>c, flat
-112	50	0.624	5.08	1.00	75	46.0	15.9	8.2	300	0.23	0.196	90	s>c, flat
-103	80	0.625	4.23	1.40	83	37.2	14.4	19.0	330	0.20	0.320	70	s>c, flat
-102	80	0.624	4.30	1.05	80	43.7	15.3	10.0	290	0.26	0.240	85	s>c, flat
-114	125	0.624	4.88	0.99	75	45.0	20.2	34.0	278	0.23	0.200	0	s, 45°
-100	300	0.625	4.21	1.02	70	35.0	18.6	25.8	194	0.27	0.254	0	s, 45°

[a] Specimens of smaller thickness.
[b] c = all cleavage.
[c] s > c = initiates by shear but converts to cleavage propagation.
[d] s = all shear.

the fabrication of an actual vessel component.

The as-received plate contained areas having a considerable amount of voids, inclusions and segregation (banding). A typical microstructure is shown in Fig. 1 where the banding can be seen. After prolonged heating at high temperature during heat treatment, the banding still persisted but to a lesser extent. The microstructure, grain size (ASTM No. 7), and hardness (160 Bhn) were essentially the same for both conditions.

The general configuration of the specimen used for the crack-notched tensile tests is shown in Fig. 2. All specimens, including the small size samples for conventional tests, were oriented such that the axis of the specimen was in a plane parallel to the width direction of the original plate—that is, transverse to the primary rolling direction. With reference to Fig. 2, the 7-in. dimension is the thickness of the plate, the 18-in. dimension is in the width direction, and the $^5/_8$-in. dimension is along the length of the plate. The procedures used for the preparation and testing of these specimens have been described.[1]

Experimental Results

Crack-notched Data

The results of the crack-notch tests are given in detail in Table 1, and some of the more pertinent data are illustrated in Figs. 3, 4, 5 and 6. The net section fracture strength (σ_N) was obtained by dividing the load at the time of fracture initiation (onset of rapid fracture) by the area between the cracks of the large flat tensile specimen. The yield strengths shown in Figs. 3 and 4 were obtained from conventional tensile tests of cylindrical bars. Complete conventional tensile data are given in Tables 2 and 3.

In the as-received condition (Fig. 3), σ_N is relatively constant over the entire temperature range from −300 to 500° F. Steels that were previously studied[1-4] in the crack-notched condition had exhibited a sharp drop in σ_N in a rather narrow temperature range. In general, the drop in σ_N is usually accompanied by a change in the mode of fracture initiation from shear to cleavage.[1] While the as-received A302B steel exhibited the characteristic types of brittle fracture[1] and a change in the mode of fracture initiation, there was no drop in σ_N. This behavior indicates that at least for the test conditions imposed, the average applied stresses which are necessary to cause fracture in the presence of an extremely sharp crack are essen-

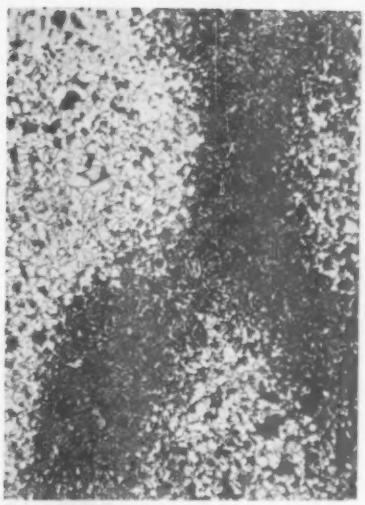

Fig. 1—Microstructure of 7-in. thick as-received A302B steel plate—transverse section, 2% nital, × 100 (Reduced 60% on reproduction)

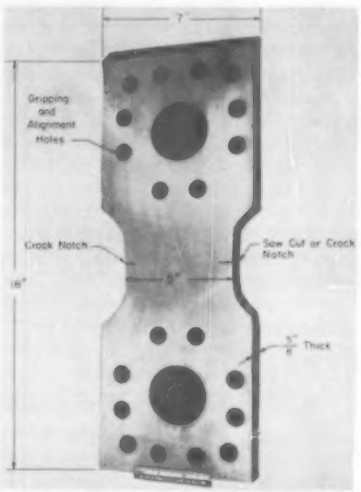

Fig. 2—General configuration of crack-notch tensile specimen

tially the same for both shear or cleavage fracture.

In the heat-treated condition also, σ_N remains relatively constant even though the mode of fracture initiation changes from shear to cleavage at about −50° F. However, σ_N does show a marked decrease between −200 and −300° F. This decrease is associated with a different change in the mode of fracture, from cleavage after moderate plastic straining to cleavage during incipient yielding. A similar behavior would also be expected in the as-received condition if it had been tested as lower temperatures (below −300° F). A comparison of the temperature ranges for the various types of fracture (Figs. 3 and 4 bottom) shows that the heat-treated condition has slightly higher ductile-to-brittle transition temperature ranges than the as-received condition.

The relative fracture resistance of the steel in the two metallurgical conditions is better shown in Fig. 5 in terms of the ratios of σ_N to the conventionally measured yield strength, σ_Y.* σ_N/σ_Y is essentially equivalent for both conditions except at low temperatures (below −50° F) where the heat-treated steel has poorer fracture resistance as illustrated by the lower ratio. At very low temperatures, average applied stresses that are considerably less than the normally measured yield strength will cause fracture. At −300° F, fracture occurs at 70% of the normal yield strength for the as-received steel and at 40% of the yield strength in the heat-treated condition. However, for both metallurgical conditions above about −150° F, average applied stresses in excess of the yield strength [$(\sigma_N/\sigma_Y) > 1$] are necessary to induce fracture even though an extremely sharp crack is initially present. Hence considerable plastic flow or forcing is required before fracture can be initiated. Since σ_N/σ_Y increases steadily with increasing temperature, fracture initiation becomes progressively more difficult. For example, at room temperature applied stresses that are 1.4 times the yield strength are required for fracture.

The somewhat greater fracture resistance and lower transition temperature range of the as-received steel are also demonstrated in Fig. 6 in terms of the ductility and fracture appearance of the crack-notched tests. The characteristic types of fracture have been reported in detail in an earlier paper[1] and the general appearance of fracture surfaces of the A302B steel are described in Table 1. Photographs representing the different types of fractures that were obtained at different temperatures are shown in Fig. 7 for the as-received condition. Similar fractures were observed for the heat-treated steel but in somewhat higher temperature ranges.

Conventional Tensile Data

The detailed tensile data for both the as-received and heat-treated conditions are given in Tables 2 and 3. The pertinent strength properties are compared in Fig. 8. Here it is shown that the heat-treated steel has a higher fracture strength (load at fracture divided by the area at fracture) over the entire temperature range from −300 to 800° F. Likewise, the ultimate and yield strength of the heat-treated steel is also greater, particularly at the higher temperatures. A comparison of the tensile ductility is shown in Fig. 9. In general, the heat-treated steel is also slightly more ductile over the entire temperature range. On the basis of these tensile properties alone, the greater strength and better ductility of the heat-treated steel would certainly indicate that the thermal treatments received during fabrication of a pressure vessel did not harm the mechanical properties. However, as has already been demonstrated in the previous section the heat treatment does lower fracture resistance and raise the transition temperature range when tested in the presence of a

* The ratio of σ_N (fracture strength in pre-cracked condition) to σ_Y (the conventional yield strength) will be used as a measure of notched fracture toughness in the subsequent portion of this paper.

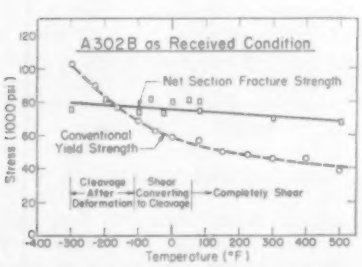

Fig. 3—Crack-notch fracture strength and conventional yield strength as function of test temperature

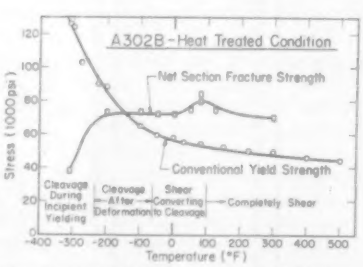

Fig. 4—Crack-notch fracture strength and conventional yield strength as function of test temperature

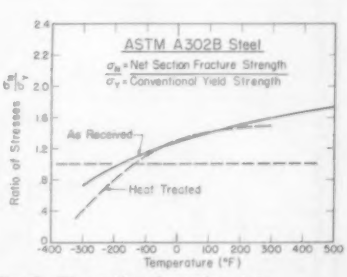

Fig. 5—The ratio of crack-notch fracture strength to yield strength

Table 2—Conventional Tensile Properties of A302B Steel As-received Condition Strain Rate, 1×10^{-3} sec^{-1}

Specimen No.	Test Temp., °F	Nominal strength, psi, load/original area					True stress at fracture, load/final area	Elongation, %			Reduction in area, %	Brittle fracture, %
		Proportional limit[a]	Upper yield	Lower yield	0.2% yield	Ultimate		Yield point	Uniform	Total		
A302B -1	−300	106,200	108,200	103,400	107,000	...	131,500	3.45	...	12.20	11.62	100
-10	−230	90,200	90,600	83,800	87,400	105,200	163,750	3.48	15.00	21.88	43.70	98
-9	−165	77,000	77,200	71,350	74,400	98,600	151,400	2.38	16.52	23.63	43.10	90
-2	−100	68,900	69,100	63,100	66,350	91,200	166,800	2.33	18.20	28.94	57.10	20
-11	−50	62,900	63,100	59,100	60,750	88,200	159,700	1.78	17.44	29.68	56.70	5
-3	0	58,100	58,700	55,100	56,100	83,400	145,300	1.57	17.86	26.50	54.50	0
-4	30	57,500	59,900	53,100	55,300	78,000	148,250	1.83	14.88	23.90	58.10	0
-5	R.T.	57,100	57,100	51,300	54,300	78,800	146,800	1.42	15.34	25.70	57.70	0
-12	115	42,300	53,500	50,500	46,500	74,200	128,700	1.55	12.60	20.71	53.90	0
-6	150	40,500	50,450	48,100	46,500	70,800	126,500	1.46	13.16	23.07	54.50	0
-13	225	42,100	49,500	47,900	45,200	71,200	132,300	1.24	13.77	24.51	59.70	0
-7	300	37,250	46,200	44,300	42,100	68,200	119,400	1.22	13.21	22.80	53.50	0
-14	400	36,700	46,100	45,500	42,300	67,400	109,600	1.05	11.25	19.09	47.90	0
-8	500	33,300	39,100	38,900	39,100	68,200	107,300	0.29	10.92	18.80	46.10	0
-15	600	32,700	...	...	41,700	73,900	126,000	...	11.99	20.08	50.70	0
-16	800	30,100	...	...	38,900	67,000	112,800	...	11.11	24.15	62.74	0

[a] Proportional limit, stress at 0.01% offset.

Table 3—Conventional Tensile Properties of A302B Steel Heat-treated Condition Strain Rate, 1×10^{-3} sec^{-1}

Specimen No.	Test Temp., °F	Nominal strength, psi, load/original area					True stress at fracture, load/final area	Elongation, %			Reduction in Area, %	Brittle fracture, %
		Proportional limit[a]	Upper yield	Lower yield	0.2% yield	Ultimate		Yield point	Uniform	Total		
302-H-12	−320	130,300	125,700	124,500	129,800	...	149,800	4.03	...	8.85	10.82	100
-1	−300	125,000	123,800	116,200	123,200	...	127,400	4.47	...	5.62	5.62	100
-16	−275	102,200	103,200	97,100	100,750	115,800	184,400	0.74	13.60	21.20	46.10	98
-15	−225	89,200	90,200	84,200	87,600	106,600	181,200	0.73	15.32	24.60	52.90	95
-13	−200	85,200	78,600	78,200	82,600	102,200	177,000	0.86	14.94	26.16	54.50	50
-2	−100	69,750	64,150	63,950	67,000	91,200	165,500	2.20	16.95	28.74	58.15	10
-14	−50	65,350	59,900	59,350	62,950	88,000	177,000	1.72	15.60	28.60	63.55	5
-3	0	50,550	58,100	55,300	57,550	82,600	135,250	1.57	14.43	23.48	54.50	0
-4	30	60,700	55,500	54,700	57,500	81,400	150,600	1.50	16.75	25.75	56.10	0
-5	R.T.	55,500	54,500	52,900	53,100	79,000	141,200	1.33	13.53	25.20	58.10	0
-6	150	54,000	52,500	51,650	51,850	74,600	146,000	1.30	15.76	27.60	60.70	0
-17	225	51,800	49,950	49,500	49,700	72,150	140,700	1.18	14.87	27.80	60.70	0
-7	300	50,500	49,350	47,850	48,600	71,450	124,300	1.15	14.65	22.20	52.90	0
-8	400	46,450	45,950	45,100	45,100	71,350	126,200	0.85	14.58	22.36	54.50	0
-9	500	44,100	44,230	43,600	43,850	74,900	136,300	0.45	13.63	21.10	54.50	0
-10	600	39,030	...	...	40,150	77,800	144,000	0.10	13.15	23.36	57.55	0
-11	800	32,880	...	...	41,660	68,600	137,700	...	12.83	27.16	69.15	0

[a] Proportional limit, stress at 0.01% offset.

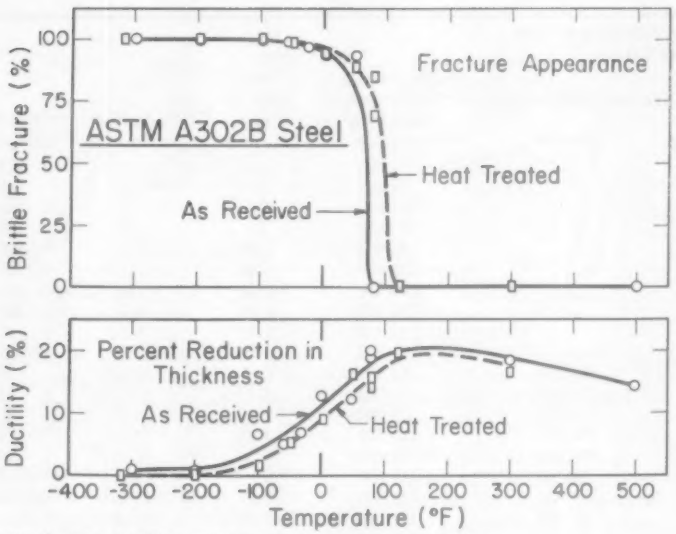

Fig. 6—The ductility and fracture appearance transition for the crack-notch tests

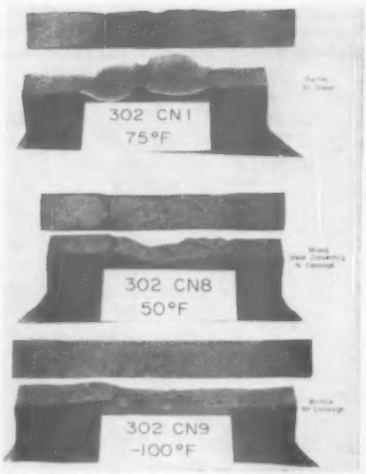

Fig. 7—Change in fracture appearance for crack-notch tests of as-received A302B steel

sharp crack. A less drastic notch effect of a similar nature is also obtained from a machined notch as may be seen from the data provided in Tables 4 and 5. Thus it is apparent that conventional tensile data alone does not provide a true indication of fracture behavior that will prevail in the presence of sharp notches or crack-like defects. The heat-treated steel, while stronger and more ductile in the absence of a notch, is more notch sensitive. Similar behaviors have been observed for other types of steel when compared at different strength levels.

Impact Test Results

Standard Charpy "V" notch impact test results are given in Fig. 10 for the steel in both metallurgical conditions. The transition temperatures as determined using the "low-blow" modification[5] of Charpy impact testing are also shown in Fig. 11. In the standard Charpy test, a difference between the two metallurgical conditions is only observed in the lower temperature portion of the transition range. Below about 150° F, the as-received steel has a higher energy absorption level and a lower fracture appearance transition. Consistent with the Charpy impact data, the "low-blow" transition temperature of the heat-treated steel is about 50° F higher at the upper inflection point and 10° F higher at the lower inflection point. Hence the results of the impact tests and the crack-notch tension tests are in good agreement with respect to the slight superiority in fracture resistance of the as-received steel.

Fracture Toughness—Strain Energy "G"

There is also another method of evaluating fracture toughness which is receiving considerable current attention. This approach involves the Griffith strain energy release rate and related size effect considerations as recently described by Irwin.[6, 7] By applying Irwin's concepts it is possible to calculate a crack extension force (G, lb per in.) from the crack-notched test data using the following expression:[8]

$$G = \frac{\sigma_G^2 L}{E} \tan \frac{\pi c}{L} \left\{1 + \frac{0.20}{1 + (\tan \pi c/L)^2}\right\}$$

where:

σ_G = gross section stress.
c = crack length.
L = total width.
E = Young's modulus.

The results are given in Tables 1 and 2. The G values for the higher temperature ranges are not meaningful since complete ductile shear fractures were obtained. Likewise, the accuracy of the other G values may be questioned, since the α values are less than the critical value of 1.0 that has been proposed by Irwin.[7] However, when the test results are considered in terms of a flat versus shear (45°) fracture appearance,[7] the G values would appear to be valid in spite of the relatively low α values. Until the question concerning flat versus shear (45°) fracture appearances is resolved, only those G values for the tests producing flat, all cleavage fractures should be considered representative of brittle fracture toughness.

Unfortunately the considerable scatter of G values for both

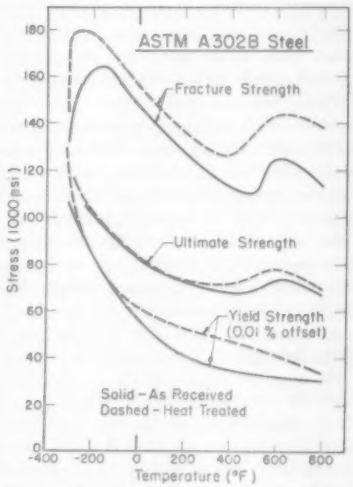

Fig. 8—The effect of temperature on the conventional tensile strength

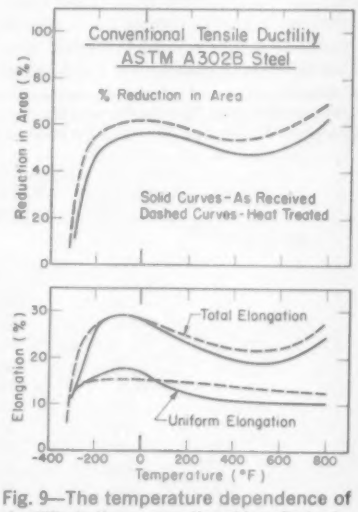

Fig. 9—The temperature dependence of ductility in the conventional tensile test

Table 4—Notched Tensile Properties of As-received A302B Steel Plate Machined Notch with $K_t = 10.8$ Estimated Strain Rate 1.0 sec^{-1}

Specimen No.	Test temp., ° F	Nominal strength, psi, load/original area At first detectable yielding	Ultimate	True stress at fracture, Load/final area, psi	Total plastic strain, ins. × 10^2	Reduction in area, %	Brittle fracture, %
302N9-19	−452	...	...	71,150	...	...	100
20	−375	...	...	75,350	...	...	100
18	−320	116,800	...	117,100	0.05	...	100
1	−300	...	...	85,150	...	...	100
16	−280	89,800	...	89,800	0.08	...	100
17	−265	133,400	...	135,800	0.06	...	100
2	−230	125,200	...	138,400	0.80	.80	100
3	−165	104,200	...	126,300	1.04	4.81	100
4	−100	91,200	...	130,200	3.55	8.62	95
5	−50	88,200	...	141,200	5.76	10.02	80
6	0	86,200	123,200	139,500	6.00	13.02	45
7	30	82,200	117,800	126,000	7.42	18.24	25
8	R.T.	96,200	115,700	126,200	7.10	18.24	15
9	150	78,150	109,400	119,700	7.10	19.65	2
10	225	70,950	105,000	111,800	7.16	20.25	0
11	300	70,200	100,200	110,500	6.92	20.25	0
12	400	65,350	99,400	111,000	5.60	18.24	0
13	500	63,150	99,200	101,300	5.00	10.02	0
14	600	54,900	99,200	112,300	4.35	14.43	0
15	800	58,100	104,600	116,200	6.14	18.24	0

conditions obscures any difference that may exist between the as-received and heat-treated material. G has been found[1, 6, 7, 9, 10] to increase with increasing temperature in several materials. Similarly, in the range for flat brittle fracture, G also increases slightly with increased temperature in the A302B steel. The increase of G with increased temperature is consistent with the behavior observed using other criteria for toughness.

Discussion

Comparison with Other Steels

A comparison of the notched fracture resistance of the A302B steel with four other steels[1, 3, 11] tested similarly is shown in Fig. 12. Here the fracture resistance as measured by the ratio of net section fracture strength (σ_N) to conventional yield strength (σ_Y) is shown as a function of temperature. The specimen and crack sizes were essentially equivalent for all the steels. It is apparent that under these particular test conditions, the A302B steel is considerably more notch fracture resistant than most of the other steels. It should be pointed out that it is not necessarily true that a steel with a higher σ_N/σ_Y ratio will also have higher absolute values of fracture strength, although this is generally the case for a given class of steels. Likewise, the same relative fracture resistance, as shown here (Fig. 12), may not prevail for larger test specimens.

The fracture resistance (σ_N/σ_Y ratio) of these several steels at room temperature can be related to the transition temperature as shown in Fig. 13. The steels with the higher transition temperatures exhibit lower σ_N/σ_Y ratios at room temperature. Such a behavior is expected since fracture resistance is known to decrease as the subtransition temperature is decreased. Hence the σ_N/σ_Y ratio that will be obtained at any given temperature will depend upon the relative position of the transition temperature.

It is, therefore, more proper to compare the fracture resistance of the various steels at their respective transition temperatures. Such a comparison is shown in Fig. 14. These data indicate that the crack-notched fracture resistance that is measured at the transition temperature decreases with increasing transition temperature. Since, in general, for steels of similar composition and thermal history, the higher yield strength steels also have higher transition temperatures, it appears that they would also have poorer fracture resistance as measured in the presence of a very sharp crack.[12]

While there are undoubtedly some exceptions to the behavior patterns just described, the trend seems to be remarkably consistent even though the type and composition of the steels vary widely. Further sub-

Table 5—Notched Tensile Properties of Heat-treated A302B Steel Plate Machined Notch with $K_t = 10.8$ Estimated Strain Rate 1.0 sec^{-1}

Specimen No.	Test temp., ° F	Nominal strength, psi, load/original area At first detectable yielding	Ultimate	True stress at fracture, Load/Final Area, psi	Total plastic strain, ins. × 10^2	Reduction in area, %	Brittle fracture, %
302-H-NT13	−320	...	...	73,750	...	...	100
2	−300	...	...	83,000	...	...	100
14	−250	...	...	134,600	...	...	100
12	−200	126,200	...	133,700	0.06	...	100
2	−100	96,200	...	124,200	1.24	4.81	100
3	0	86,200	...	132,200	4.28	7.01	98
4	30	85,200	122,300	132,600	6.45	11.62	85
5	R.T.	83,600	117,600	127,400	7.20	18.23	65
6	150	80,150	112,400	121,500	6.60	16.63	35
7	300	75,150	108,200	119,800	6.20	17.42	5
8	400	70,400	105,400	115,700	5.17	17.42	0
9	500	71,150	108,000	117,500	4.35	13.83	0
10	600	71,350	113,200	125,800	4.13	12.42	0
11	800	55,100	106,800	116,700	5.58	14.63	0

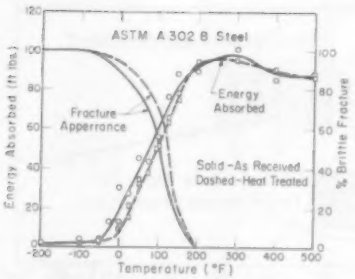

Fig. 10—Conventional Charpy "V" notch impact transition data

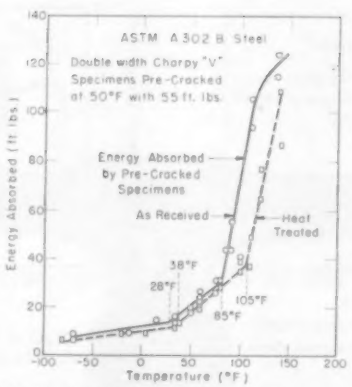

Fig. 11—Low-blow[5] Charpy impact transition data

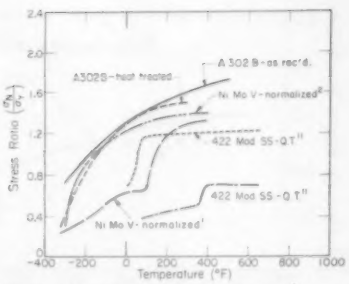

Fig. 12—Crack-notched fracture resistance of several steels as a function of test temperature

stantiation of the existence of this trend is seen from the work of Srawley and Beachem,[4] who have determined the σ_N/σ_Y fracture resistance of several high-strength steels using thin sheet specimens containing a central crack. The type and composition of these steels also varied widely, i.e., martensitic stainless steels, martensitic low-alloy steels, hot work die steels and a precipitation hardening stainless steel. When these data[4] are plotted in the same fashion as just described for the steels included in this paper, the same behavior trends are evident as may be seen in Figs. 15 and 16. Because of metallurgical considerations, the considerable difference in the size of the specimens and the differences in the criteria for transition temperatures used in the two investigations, no direct or quantitative comparisons can be made. However, on the basis of these two sets of independently obtained data it would appear that these trends may be indicative of a general behavior pattern. If this be so, one must conclude that, generally speaking, steels with higher transition temperature can be expected to have poorer inherent notch fracture resistance particularly at or below their respective transition temperature. Likewise, it is believed that for steels of similar composition, microstructure and thermal history, an increase in yield strength would have the same effects as an increase in transition temperature.

Because of the rather important implications of these observed behaviors—particularly as related to design concepts and procedures—further understanding of the influence of size effects and metallurgical variables, in particular, appears to be necessary. While the behavior trend in general will no doubt be consistent, it is believed that quantitative comparisons will only be possible within any given class of steels having similar thermal histories.

Size Effects

It must be emphasized that the fracture data which are shown for the crack-notch condition of the A302B steel, as well as the others, in this paper were obtained for a particular specimen geometry and crack size. Therefore, in their present form these data alone cannot be applied directly for specific evaluation or design purposes, particularly where heavy sections are involved. It is expected that the same behavior pattern as shown in the present crack-notch experiments will undoubtedly prevail for other geometrical conditions. However, the occurrence of brittle fracture will be shifted to different stress (σ_N) and probably different temperature levels. An increase in total section size, while maintaining a constant ratio of crack to section size, will decrease the fracture strength in proportion to the inverse square root of the crack length.[6, 7, 9, 10] A similar behavior is observed[1] when crack length is increased while maintaining a constant section size. Thus, tests of larger specimen sizes would be expected to result in lower σ_N/σ_Y ratios at higher temperatures.

It must further be appreciated that the comparisons of the A302B steel in two metallurgical conditions, as well as the comparisons with other steels, are only applicable to the specific geometrical configuration that was employed. Because of possible variation in size effects from one steel to another, it cannot be conclusively stated at the present time that the same relative fracture resistances as measured in the present experiments would prevail if the comparisons were based on data obtained using another size of specimen. It is anticipated that this point will be resolved in the course of continued experimental work.

Although the present study of the A302B steel did not include the effects of radiation damage on fracture resistance, this aspect would have to be considered in the application. Radiation damage is known[13] to raise the ductile-to-brittle transition temperature and lower the steels' energy absorption ability as

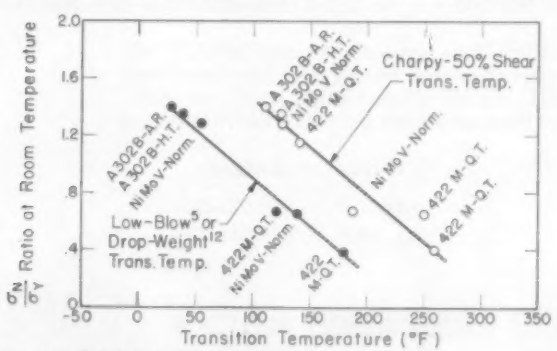

Fig. 13—Effect of transition temperature on the room temperature strength ratio

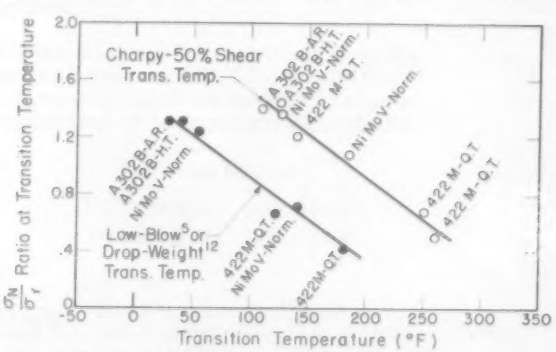

Fig. 14—Effect of transition temperature on the strength ratio at the transition temperature

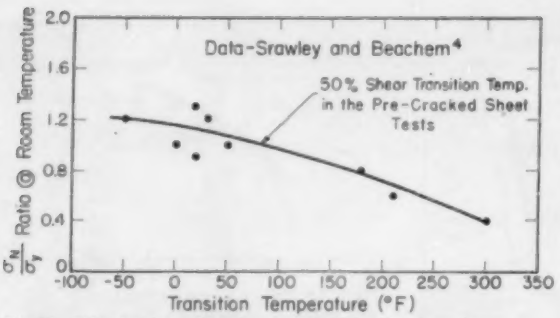
Data-Srawley and Beachem[4]
50% Shear Transition Temp. in the Pre-Cracked Sheet Tests
$\frac{\sigma_N}{\sigma_Y}$ Ratio @ Room Temperature
Transition Temperature (°F)

Fig. 15—Effect of transition temperature on the room temperature strength ratio of several high-strength sheet steels

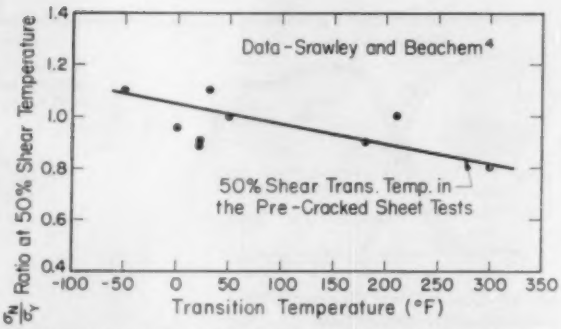
Data-Srawley and Beachem[4]
50% Shear Trans. Temp. in the Pre-Cracked Sheet Tests
$\frac{\sigma_N}{\sigma_Y}$ Ratio at 50% Shear Temperature
Transition Temperature (°F)

Fig. 16—Effect of transition temperature on the strength ratio at the transition temperature of several high-strength sheet steels

measured by the Charpy impact test. Hence, similar effects of radiation on fracture resistance could be expected in the crack-notch tests.

Summary

The brittle-fracture characteristics of ASTM Type A302B steel were studied in considerable detail. Primary emphasis was given to determinations of fracture resistance using large flat tensile specimens containing relatively large, pre-existing, sharp edge cracks. The steel was studied in both the as-received (normalized) condition and after a heat treatment consistent with the thermal cycles that the steel subsequently encounters during fabrication of a reactor pressure vessel. The heat-treated steel was found to have a slightly higher transition temperature range, and to be less notch fracture resistant below −50° F. For the cracked-notched conditions and specimen sizes that were used, average applied stresses in excess of the normally measured yield strength were required for fracture at temperatures above −125° F for the heat-treated condition and above −175° F for the as-received condition. Below these temperatures fracture occurred at applied stresses less than the normally measured yield strength. Larger specimen sizes could be expected to demonstrate poorer fracture resistance; that is, lower σ_n/σ_y ratios at higher temperatures.

In comparison with most other steels that have been studied (under equivalent conditions), the A302B material in both metallurgical conditions has considerably more brittle fracture resistance. However, because of possible variations in size effects in different steels it is not conclusively known whether or not the same relative fracture resistances would prevail if the comparisons were based on data obtained using a different size specimen. Further investigation is expected to resolve this question.

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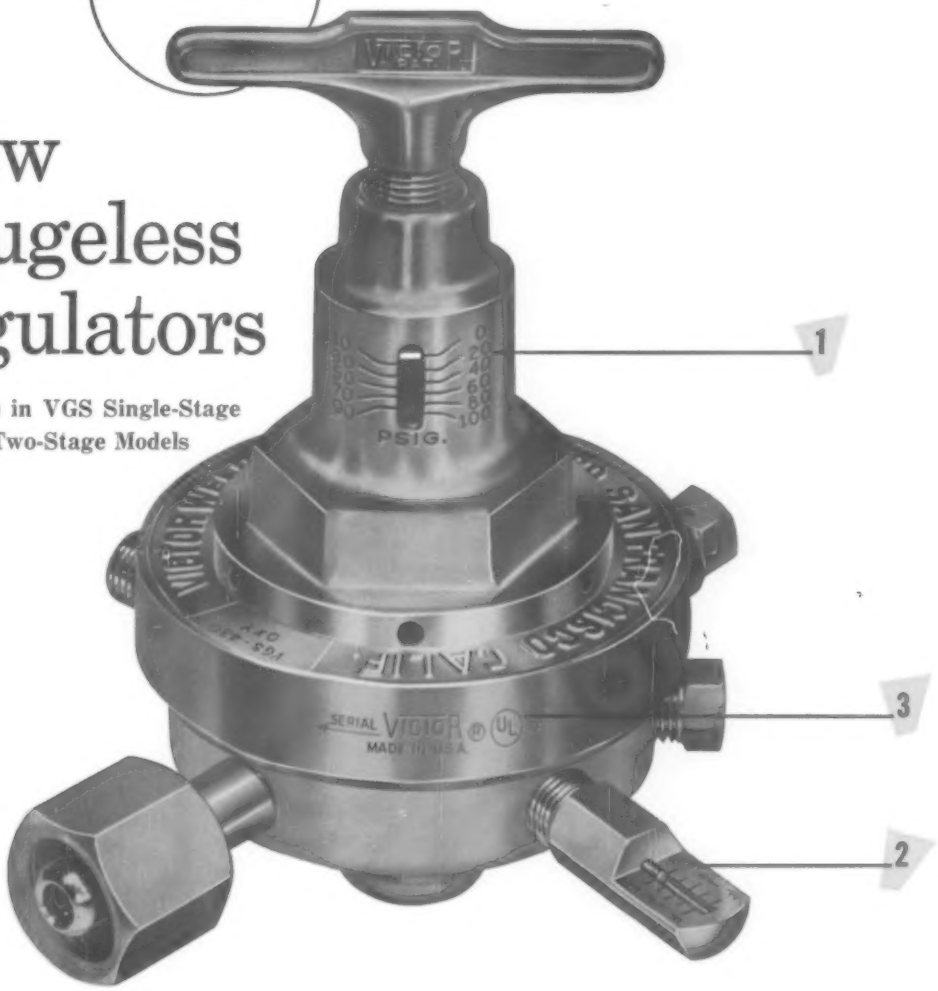

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